RRS-022

Reusable Reentry Satellite (RRS) Summary Report

Recovery Tradeoff Study

March 1990

Contract NAS9-18202
DRL 02

Prepared for:

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

SAIC®
Science Applications International Corporation
21151 Western Avenue • Torrance, California 90501 • (213) 781-9022

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FOREWORD

The Reusable Reentry Satellite (RRS) Recovery Tradeoff Study described herein was performed during Part 1 of the RRS Phase B contract. This report is one of several that describes the results of various trade studies performed to arrive at a recommended design for the RRS satellite system. The overall RRS Phase B Study objective is to design a relatively inexpensive satellite to access space for extended periods of time, with eventual recovery of experiments on Earth. The RRS will be capable of: 1) being launched by a variety of expendable launch vehicles, 2) operating in low earth orbit as a free flying unmanned laboratory, and 3) executing an independent atmospheric reentry and soft landing. The RRS will be designed to be refurbished and reused up to three times a year for a period of 10 years. The expected principal use for such a system is research on the effects of variable gravity (0-1.5 g) and radiation on small animals, plants, lower life forms, tissue samples, and materials processes.

This Summary Report provides a description of the RRS Recovery Tradeoff Study performed to identify recovery options, recovery sites, post-recovery access timelines, interfaces, terminal landing systems, terminal landing system accuracies, conceptual design specifications, integration issues, and cost.

The study was performed under the contract technical direction of Mr. Bob Curtis, SAIC Program Manager. The Launch Vehicle Tradeoff Study was performed by Eagle Engineering, via subcontract from SAIC, under the direction of Mr. William Davidson. Mr. Michael Richardson, JSC New Initiatives Office, provided the RRS objectives and policy guidance for the performance of these tasks under the NAS 9-18202 contract.

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LIST OF ABBREVIATIONS AND ACRONYMS

AFB	Air Force Base
AI	Artificial Intelligence
APM	Attitude/Propulsion Module
ARC	Ames Research Center
CAD	Computer Aided Design
CCAFS	Cape Canaveral Air Force Station
CDR	Critical Design Review
CONUS	Continental United States
COTS	Commercial Off-The-Shelf
CR	Change Request
DDT&E	Design, Development, Test and Evaluation
DMS	Data Management System
DoD	Department of Defense
DRM	Design Reference Mission
ΔV	Delta Velocity
ECLSS	Environmental Control and Life Support System
EEI	Eagle Engineering, Inc.
EM	Experiment Module
EPS	Electrical Power System
ETR	Eastern Test Range
GCEM	Ground Control Experiment Module
GNC	Guidance Navigation and Control
GPS	Global Positioning System
GSE	Ground Support Equipment
JSC	Johnson Space Center
KSC	Kennedy Space Center
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NSTS	NASA Space Transportation System
OTS	Off-The-Shelf
PI	Principal Investigator
PM	Payload Module of the RRS
POCC	Payload Operations Control Center

LIST OF ABBREVIATIONS AND ACRONYMS (Cont.)

RMOAD	Reference Mission Operational Analysis Document
RRS	Reusable Reentry Satellite
RRV	Reusable Reentry Vehicle
SAIC	Science Applications International Corporation
SM	Service Module
SRB	Solid Rocket Booster
SRD	System Requirements Document
STS	Space Transportation System
TBD	To Be Determined
TDRSS	Tracking and Data Relay Satellite System
WSMR	White Sands Missile Range
WTR	Western Test Range

EXECUTIVE SUMMARY

The main objectives of the Recovery Tradeoff Study were as follows: 1) to determine whether a land or water recovery best suits RRS system requirements, 2) what type of terminal recovery system is best suited for the RRS, and 3) what are the recovery access timelines after system landing. Based on the trade parameters and evaluation criteria used in this study, the land-landing configuration has an advantage over the water-landing configuration. It is recommended that a land-landing configuration be developed assuming WSMR as the landing site. It is also recommended that natural orbits be used for low inclination missions and any orbit adjustments for landing site targeting be performed at the end of the mission. Near-integer orbits should be used for high inclination missions and allow orbital decay to precess the ground track over the landing site range.

Evaluation of the landing system design options narrowed the choice down to either a conventional parachute system or an actively controlled gliding parachute with passive impact attenuation. The conventional parachute system will meet the requirements of the RRS at a minimum of risk for design and cost. It is based on a mature technology where the design parameters are well understood. The gliding parachute system potentially reduces vertical impact loads and offers some operational performance advantages in terms of landing accuracy and recovery timelines. It also has a minor advantage in terms of hardware weight and volume. These advantages are countered by higher development risks, development costs, and hardware costs, as well as test program complexity.

The development and analysis of the recovery and EM access timelines indicate that it is feasible to accomplish the operation within the 2-hour limit specified. It is recommended that the option of helicopter return of the RRV and removal of the EM at the Post-Recovery facility be baselined. It is also recommended to constrain the landing sites to be within the range of 40 nm from the Post-Recovery facility and to move the Post-Recovery facility to a more central location than the NASA Test Facility. It is recommended that NASA coordinate range scheduling and range usage priorities to ensure that top priority be given to support the RRS mission during critical periods following launch and preceding planned landing. A lower priority for range usage and recovery support can be used for the majority of the mission duration where the need for rapid support and range clearance is not as critical an issue. This is necessary to share the range with other users and to minimize the operational cost of maintaining range and recovery personnel on immediate standby for the duration of the mission.

1.0 INTRODUCTION

1.1 Background

As currently conceived, the Reusable Reentry Satellite (RRS) will be designed to provide investigators in several biological disciplines with a relatively inexpensive method of access to space for up to 60 days with eventual recovery on Earth. The RRS will be designed to permit totally intact, relatively soft recovery of the vehicle, system refurbishment, and reflight with new and varied payloads. The RRS system will be capable of 3 reflights per year over a 10-year program lifetime. The RRS vehicle will have a large and readily accessible volume near the vehicle center of gravity for the payload module (PM) containing the experiment hardware. The vehicle is configured to permit the experimenter late access to the PM prior to launch and rapid access following recovery.

The RRS will operate as a free-flying spacecraft in orbit and allowed to float in attitude to provide an acceleration environment of less than 10^{-5} g's. The acceleration environment during orbital trim maneuvers will be less than 10^{-3} g's. The RRS is also configured to spin at controlled rates to provide an artificial gravity of up to one Earth g. The RRS system will be designed to be rugged and easily maintainable, and economically refurbishable for the next flight. Some systems may be designed to be replaced rather than refurbished if cost effective and capable of meeting the specified turnaround time. The minimum time between recovery and reflight will be about 60 days.

The PM's will be designed to be relatively autonomous with experiments which require few commands and limited telemetry. Mass storage, if needed, will be accommodated in the PM. The start of the hardware development and implementation phase is expected in 1991 with a first launch in 1993.

Numerous trade studies and RRS functional design descriptions are required to define a RRS concept which satisfies the requirements and is viable. NASA has contracted with the Science Applications International Corporation (SAIC) to perform a phase B study to provide the RRS concept definition. Eagle Engineering, Inc. is supporting SAIC in accomplishing the necessary studies. The Recovery Tradeoff Study is one of the supporting study analyses performed by Eagle. The other Eagle studies are the Launch Tradeoff Study, the Missions Operations Design Definition, and the Analytical Support Studies.

1.2 NASA JSC Statement of Work Task Definition

Conduct required study with depth of analysis as appropriate to clarify and document the viability of each approach. Give particular attention to effects of complexity, flexibility, or imposed constraints on the RRS design, RM design, or mission operations. Also, special consideration should be given to system reliability and operational safety as well as the reduction in program life cycle costs.

a. Consider the recovery planning and landing system impacts for RRS designs that jettison a portion of the structure and/or subsystem components in orbit prior to the start of the initiation of the retro maneuver.

b. Consider the advantages and disadvantages of landing the RRS at a continental U.S. ground site or an ocean recovery site. In both cases, consider the effects of subsystem failures on the mission and public safety, the logistics associated with recovery operations, payload processing at the recovery site, and the subsequent transportation of the payload and RRS system for processing and refurbishment.

c. Determine the effect of the RRS (including payload) configuration and mass on the recovery planning aspects and landing system tradeoff and specifications. Identify any public safety issues and the range capability required to meet the recovery scenarios. Identify all recovery terminal phase system components that require development.

d. Consider RRS designs which limit landing shock loads during the recovery process, e.g., designs which use deployable air bags or crushable material; designs which are captured in nets or land on a prepared shock absorbing surface; and designs which land horizontally on skids.

e. Determine the tradeoffs between quick access to the payloads following recovery and RRS design and safety issues.

f. Prepare a complete description of the reference system design for the RRS terminal phase system (atmospheric deceleration, landing, and retrieval) including functional description and complete conceptual specifications.

g. Prepare a preliminary cost estimate for the development, fabrication, and test of the first RRS terminal phase system and estimate the cost of a second flight unit and spares.

1.3 Scope

This NASA phase B study is intended to provide the RRS concept definition. The study includes tradeoff studies with the depth of analysis as appropriate to clarify and document the viability of each approach. The RRS system and operations are developed to the degree necessary to provide a complete description of the conceptual designs and functional specifications. Detailed engineering designs are not produced during phase B studies since the significant resources are allocated and reserved for the subsequent phase C/D design and implementation activities. Therefore, many analyses and definitions in this study are based on engineering experience and judgement rather than detailed design calculations.

2.0 STUDY APPROACH

2.1 Organization

The study is organized to be accomplished in a series of related but separate tradeoff studies and system concept definitions. Therefore, the documentation has been formatted to accommodate a compendium of analyses which are published in one document for recovery tradeoff. The document is produced in a series of report iterations in the form of interim reports which culminate in the publishing of the final report at the midterm of the RRS Phase B Study.

2.2 Document Format

Although the individual analyses and studies are not amenable to documentation in exactly the same topical arrangement, a general outline is used where reasonable. The guideline outline for preparing the individual study sections is provided below:

- Purpose
- Assumptions and Groundrules
- Tradeoff Options
- Analysis
- Recommendations
- Conclusions

2.3 Assumptions and Groundrules

In the process of performing the subject trade study, certain data or study definition was not available or specified. Assumptions and groundrules have been established to document, for the purposes of this trade study, the definition of important information which is not a definite fact or is not available in the study time period. Specific assumptions are listed in the section where appropriate. General assumptions and groundrules which affect all studies are listed as follows:

1) Where project, hardware, and operations definition has been insufficient, detailed quantitative analysis has been supplemented with assessments based on experienced judgement of analysts with space flight experience from the Mercury Project through the current time.

2) The RRS missions to be supported are those baselined in the mission operations design definition study and referred to as RRS design reference missions (DRM's). The RRS design reference missions are identified in Table 2.3-1.

Table 2.3-1. Design Reference Mission Set Definition

Definition Parameter	Design Reference Mission Set				
	DRM-1	DRM-2	DRM-3	DRM-4	DRM-5
Character	Land Recovery	High Altitude	High Inclination	Integer Orbits	Water Recovery
Inclination	33.83°	33.83°	98°	35.65°	28.5°
Orbit Type	Circular	Circular	Circular, Near-Integer	Circular, Integer	Circular
Orbit Altitude	350 km (189 nm)	900 km (486 nm)	897 km (484 nm)	479 km (259 nm)	350 km (189 nm)
Launch Site	Eastern Test Range (ETR)	Eastern Test Range (ETR)	Western Test Range (WTR)	Eastern Test Range (ETR)	Eastern Test Range (ETR)
Recovery Site	White Sands Missile Range (WSMR)	White Sands Missile Range (WSMR)	White Sands Missile Range (WSMR)	White Sands Missile Range (WSMR)	Water (ETR, Gulf of Mexico, WTR)

3.0 RRS LAND VERSUS WATER RECOVERY TRADEOFF STUDY

3.1 Purpose

The purpose of this study is to investigate the advantages and disadvantages of landing the Reusable Reentry Satellite (RRS) at a continental U.S. ground site or a water recovery site. The key program goals driving this choice were that the RRS design must (1) assure public safety, (2) meet science needs, (3) produce an affordable solution, and (4) minimize the need for operational support. In performance of this trade study, documentation of the design, operation, and economic choices which affect the final decision of the operating method for landing and recovery of the RRS will serve to provide a basis for subsequent trades and design analyses. This study will consider those effects of subsystem failures on the accomplishment of the mission, assurance of public safety, implementation of Payload Module (PM) and RRS recovery, and subsequent processing or refurbishment. Once the issue of safety is addressed, the trade analysis will evaluate the effect of the landing mode on RRS design and PM design. Attention will also be given to the impact of the landing mode on operational complexity, flexibility, and constraints. Special consideration will be given to the economic impact of the landing mode on discreet aspects of operations and design as well as the overall life cycle cost.

3.2 Approach

This study will be focused upon the landing and recovery phase of the mission, but will identify impact of landing mode on other phases of the mission operations. Consideration will be given to the recovery planning and terminal phase system impacts of RRS design that jettison a portion of the structure and/or subsystem components prior to entry.

The approach used in this study was to start with the SAIC Team proposal design configuration as the basis for a land landing RRS design. From this design a water landing design was synthesized with sufficient definition on mission operations and recovery operations so a comparative evaluation of major differences could be evaluated. Applicable requirements were identified which impacted the design and operational considerations of each approach.

For each design approach, the critical mission events affecting public, mission, and operational safety were identified. From these critical events, the impact on vehicle design as well as operations were discussed and potential solutions offered to minimize the safety risk. Affected vehicle subsystems were identified, but the detailed design impact was left to the vehicle designer.

It was recognized that the use of water landing areas is intrinsically a safer approach, but the vehicle could be designed to provide additional features to assure public safety with land landings to gain benefits affecting science objectives, refurbishment costs and operations costs.

A set of operational parameters were identified as major factors which influence the method of landing and recovery. These parameters were individually assessed as to their suitability to support land or water recovery. A subjective rating was given to each parameter with consideration for science objectives, vehicle design and operational aspects.

The final evaluation process was based on the ability to meet the science needs, to produce an affordable design, and to minimize operational complexity. Each of these goals were evaluated on the basis of specific evaluation criteria, each of which were a composite of four of the operational parameters. The individual parameter subjective value was multiplied by a weight factor, which represented the relative importance of the evaluation criteria, and the weighed scores were summed to identify the preferred approach to vehicle recovery.

3.3 Water versus Land Tradeoff Assumptions and Groundrules

3.3.1 General Assumptions and Groundrules

- Cost evaluation will be limited to recovery and refurbishment related issues. Life cycle costs will be assessed later. These costs includes DDT&E, hardware procurement, mission operations, and mission turnaround.
- All science and mission objectives other than the choice of landing site location and method must be met.
- A water landing RRS will use the same terminal landing system design as the land landing RRS.
- The Experiment Module and RRS can be recovered provided that 7 days notice is given prior to early mission termination.
- An emergency termination of the mission can be accomplished within twenty-four (24) hours without assurance of experiment survival.

3.3.2 Land Landing RRS Design and Operations Concept

3.3.2.1 Vehicle Design

The design of the RRS vehicle considered in this trade study is basically derived from the Technical Section of the SAIC Team Phase B Study Proposal (Reference 3). The configuration consists of a basic vehicle containing the Payload Module (PM), a Service Module (SM), and an Attitude/Propulsion Module (APM). The PM is further subdivided into the Experiment Module (EM) and its associated support equipment. The basic vehicle components will be able to be separated into two interconnected masses in orbit by Astromasts to allow spinup and artificial G levels without inducing undesirable rotational effects. Deorbit ΔV will be provided by the APM as well as attitude control for entry capture. The terminal descent system consists of a parachute and terminal landing impact attenuation system. To cushion the final impact and stabilize the vehicle, air cushion bags or crushable material are located in the base area of the vehicle.

3.3.2.2 Mission Operations

Mission operations require that the RRS be launched into an orbit whose inclination will cross the selected Continental United States (CONUS) landing site. For the purpose of this trade, the landing site is assumed to be White Sands Missile Range (WSMR) in New Mexico. In the Ames Research Center Concept Feasibility Study (Reference 2), the RRS recovery was based on the use of integer orbits which would allow repeated landing opportunities each day. To accomplish this, the RRS must correct any launch insertion errors and accomplish phasing maneuvers if it was launched on a shared vehicle whose orbit did not coincide with an orbital track that crosses the landing site. Since the primary consideration for integer orbits was to allow daily landing opportunities at the landing site and not for science or experiment needs, any phasing maneuvers could be accomplished near the end of the mission. This would minimize the need to perform precision orbit insertion adjustments and orbital period decay adjustments during the mission. To perform the final deorbit phasing maneuver, the RRS vehicle would have to be despun and collapsed to the deorbit burn configuration. In this configuration, it is desirable to minimize the time on-orbit preceding the deorbit burn due to thermal control considerations.

The deorbit burn is accomplished using the APM propulsive capabilities with burn trim adjustment to minimize the downrange dispersions. Reentry is ballistic and the entry profile is determined by vehicle shape and de-orbit conditions. By retaining all of the vehicle components during de-orbit and reentry, it is expected that hazards associated with reentry debris will be eliminated.

3.3.2.3 Recovery Operations

The terminal descent of the RRS will be tracked by the WSMR radars and other tracking devices to determine the landing point. The Ground Support Equipment (GSE) necessary to support the PM for power and thermal control will be deployed to the landing site with WSMR range support helicopters. At the landing point, the RRS will be checked for hazards and the GSE will be connected to the PM to support the experiments. Depending upon time constraints, the PM could either be removed from the RRS at the landing site or at some facility located on the range. Once the PM is removed from the RRS and the responsibility for the PM handed to the experimenter, the post-recovery phase of the experiment is considered completed. Recovery of the RRS without the PM still requires safing of hazardous systems. The safing operations typically involve installation of shorting plugs on all pyrotechnic initiators, disconnection of power sources, and removal of all propellants from the APM. With the completion of these activities and shipment of the RRS to the refurbishment facility, the post-recovery phase of the RRS operation is considered closed.

3.3.3 Water Landing RRS Design and Operations Concept

3.3.3.1 Vehicle Design

The basic design of the RRS will be the same as that described for the land landing RRS. Specific design differences would include provisions for flotation, at-sea location, and protection for water immersion. Such design changes may have significant design and economic penalties. Other potential differences may be less stringent redundancy requirements on the GN&C and propulsion systems as well as the exclusion of the need for impact attenuation. Secondary impact attenuation devices are not considered necessary for a water landing vehicle due to the cushioning effects of water landing.

3.3.3.2 Mission Operations

Mission operations with the use of water landing sites may be enhanced by the relief of the need to constrain the landing site to the same limits as those imposed by land landing sites. For this reason, the option to use natural orbits relieves the need for orbit adjustment after insertion.

Another factor that the water landing approach would provide is the ability to deliver the RRS into a due east orbit low inclination orbit which would maximize the launch vehicle delivery capability. It may also reduce the need for deorbit phasing maneuvers unless it is decided to also constrain the area of the landing site for operational reasons. A constraint that water landing imposes on mission operations is a more severe restriction of allowable weather conditions at the landing sites due to the effects of winds upon sea state surface conditions which will limit operational capability for recovery.

3.3.3.3 Recovery Operations

For a water landing vehicle, tracking of the entry and terminal landing trajectory may be accomplished by trajectory prediction programs and spacecraft data. Location of the vehicle prior to and following landing may be dependent upon transponders and other location aids. If surface vessels are involved, they would be located adjacent to the ground track near the predicted landing point. After landing, it is anticipated that the recovery vessel would home on the recovery beacon and retrieve the RRS with a hoist. Once onboard, the RRS would be checked for hazardous conditions and connected to the GSE after safing. With this operation, it is expected that the PM would be removed while onboard the recovery vessel since it would not be practical to return to land within the time constraint imposed by the experiments. Return of the PM to a land base on short notice would be possible if a helicopter transfer was involved. Another alternate would be to have a helicopter recover the entire vehicle and return it directly to a land base.

3.4 Applicable Requirements

The Reusable Reentry Satellite (RRS) System Design Study Statement of Work (Reference 1) was reviewed for requirements which may have an impact on the choice of landing site and landing method chosen for the RRS. The following requirements were considered directly applicable to this study:

Reference 1 Paragraph No.	Requirement

3.1.1. Operational Frequency and Lifetime

Each RRS shall be capable of being refurbished and relaunched in 60 days following recovery in order to support up to three (3) missions per year over a ten (10) year period.

3.1.4. Reusability

The RRS shall be designed in a manner that vehicle structure and system elements are reusable for multiple missions wherever it is cost effective to do so.

3.1.7 Recovery Operations

The RRS shall be designed for safe operations during de-orbit and surface recovery. The RRS shall be designed to de-orbit so as to allow a near-vertical descent from an altitude of at least 60,000 ft with a 3 sigma probability of a footprint within a crossrange dispersion of ± 6 km and a downrange dispersion of ± 30 km. The recovery system shall be designed to avoid a violation of the selected controlled recovery zone airspace.

3.2.3.1 Operational Orbits

The RRS shall have the capability of operating and returning from orbits within the altitude range of 350 to 900 kilometers with inclinations between 34° and 98° as well as elliptical orbits that require similar ΔV.

3.2.4.2 Terminal Descent and Recovery

The RRS shall have the capability to perform de-orbit, reentry and terminal descent maneuvers with sufficient accuracy and control to enable rapid, efficient recovery of the PM at the designated recovery site. Parachute deployment or other atmospheric braking device shall not cause more than 2 g's axial load. The "ground impact" shall not exceed 10 g's along any axis.

3.2.5.1 PM Access - Post Recovery

The RRS shall have the capability for providing physical access to the PM within two hours of ground touchdown. Provisions shall be made to provide thermal control and electrical power to the PM (via Ground Support Equipment) within TBD minutes of ground touchdown.

3.2.5.2 <u>Refurbishment Time</u>

The RRS shall be capable of being refurbished and ready for integration with a PM for a subsequent mission within sixty (60) days after recovery of the prior mission.

3.2.10 <u>Safety Requirements</u>

The safety of the RRS, the flight experiments, ground personnel, the public, and the prevention of damage to property, and to ground and flight hardware shall be a prime consideration in the total system design. The design tradeoff studies shall include an evaluation of the measures to be employed to prevent both inadvertent operations and the occurrence of hazardous conditions during all phases of development, testing, operations, and refurbishment. The design evaluation shall include the impact on other equipment, payloads, personnel, and public safety as a result of malfunctions, failures, and abnormal spacecraft performance.

3.3.5.5 <u>Recovery Phase</u>

The RRS Thermal Control System shall be designed to minimize the reentry heat soak into the internal cavity of the vehicle and to minimize the increased RRS PM temperature. The design shall allow thermal control via GSE to be applied to the PM within TBD minutes of ground touchdown.

3.3.6 <u>Attitude Control and Propulsion Subsystem</u>

The RRS Attitude Control and Propulsion Subsystem shall provide the following capabilities:

(f) Correct launch errors in the orbital parameters and adjust the parameters to be compatible with the recovery site requirements.

3.3.8 <u>Recovery Subsystem</u>

The RRS Recovery Subsystem design shall provide adequate dynamic and static stability to control the RRS flight path with sufficient accuracy to permit recovery within the designated recovery area. The forces experienced by the RRS during this mission phase shall not exceed those specified in Paragraph 3.2.4.2.

4.2.4.2 <u>Post - Recovery Timeline</u>

The RM design shall satisfy a Post-Recovery timeline which includes: connection of ground cooling and power by impact plus TBD minutes; delivery of the RRS to the Post-Recovery Facility by impact plus TBD minutes; and removal of the flight animals by 2 hours after impact.

3.5 Water versus Land Recovery Safety Impacts

The safety impact caused by the choice of landing method fall into three primary areas. These areas are due to potential damages and injuries cause by missed target area landings, debris generation, and post landing subsystem hazards. The probable cause and potential solutions for both land and water landing RRS designs are summarized in Table 3.5-1.

A difficult problem with respect to public safety is to provide assurance that the potential for injury or property damage is minimized and is an acceptable risk in the event of potential targeting errors. The source of these errors can come from deorbit burn errors, post deorbit burn dispersions, and subsystem malfunctions. Deorbit burn errors can arise from errors in vehicle attitude at the time of firing, errors in timing, and errors in total ΔV magnitude. Deorbit thrust tailoring can minimize some of these errors. Both the land and water landing vehicle design must contain a level of subsystem redundancy and reliability to assure that the vehicle will land in the designated target area to accomplish mission recovery. For a land landing vehicle design, provisions to monitor critical events and enable command override of critical events may be necessary to assure that these errors will not allow the vehicle to land outside the safety area of the range. As a backup measure, the ability to stop critical events, once a major error has been identified and cause a fail safe entry into open ocean areas may be necessary for the land landing vehicle. For the water landing vehicle, a sufficient buffer zone between the target area and any populated land mass may be adequate to assure safety in the event of a deorbit burn error.

Potential causes for landing dispersions after the deorbit burn has been completed come from uncertainties due to entry atmosphere density and surface winds. As long as these dispersions are within the allowable limits of the target zone, they do not pose a significant safety issue. To minimize these dispersions for a land landing vehicle, several methods can be employed to assure mission success. One method to constrain the atmospheric density dispersion is to adjust the entry angle so the dispersions remain within the desired limits. Wind drift can be minimized by lowering the opening altitude of the main parachute or by employing a gliding parachute to compensate for the drift. For an ocean landing vehicle, it is assumed that any dispersion caused by the atmosphere density or surface winds would not impact public safety as long as a sufficient buffer zone exists around the landing area.

Subsystem malfunctions constitute the most difficult problem to address with respect to landing safety. To avoid safety problems caused by missed target area landings, a land landing RRS should have its critical systems designed to fail operational. The subsystems that are of major

Table 3.5-1. Critical Parameters Affecting Public Safety

Missed Target Area	Potential Solutions: Land	Potential Solutions: Water
• Deorbit Burn Errors - Attitude - Timing - Duration	- Subsystem redundancy - Ground monitoring and critical event command override - Fail safe ocean entry	- Subsystem redundancy - Increased dispersion area buffer zone
• Landing Dispersions - Entry atmosphere - Density - Surface winds	- Constrain trajectory - Miminize parachute deployment altitude - Provide gliding parachute	- Increase dispersion area buffer zone - Wind drift is allowable
• System Malfunctions - GNC - Propulsion	- Critical systems must fail operational	- Critical systems must fail safe and must have sufficient safe landing area
Debris • Vehicle Components - Propulsion module - Heat shield	- Constrain vehicle design - Limit deployment altitude of heat shield	- Increase landing area buffer zone - Limit deployment altitude of heat shield
Post Landing Hazards • Fire • Toxics • Pyrotechnics	- Select non-hazardous sites - Provide adequate buffer zones - Test for toxics - Provide safing circuit	- Site has natural protection - Inspect for toxics - Provide safing circuits

importance in this area are the GNC, propulsion, and sequencing subsystems. A water landing RRS can be designed to have its critical subsystems fail safe as long as a sufficient buffer zone exists to accommodate the dispersions created by a subsystem malfunction. In some cases such as deorbit burn termination, critical event override may be desired to avoid the need for excessively large buffer zones.

Debris generation can be avoided for either land or water landing vehicle designs. Both design concepts have incorporated integral propulsion systems to avoid the problem of debris dispersal over the ground track. Potential problems of debris hazard from a separated heat shield can be avoided for both vehicle concepts by limiting the deployment altitude or by using a retention lanyard if the separated heat shield size is small.

Post-landing hazards due to potential risk for fire, toxic vapors and unfired pyrotechnics can be addressed through vehicle design and site selection. The potential for surface fires created by a land landing vehicle is minimized by selecting a landing zone with limited surface vegetation and by designing proper safeguards into the propulsion system. The same safeguards would have to be designed into a water landing vehicle to avoid potential safety risks to the recovery personnel. Subsystem design and operational procedures to avoid risks of personnel injury due to toxic vapors or unfired pyrotechnics must be the same for both land and water landing vehicle designs.

3.6 Water versus Land Recovery Trade Options

3.6.1 Orbit Setup

The use of integer orbits, as discussed in an Ames study (Reference 2), appears to be considered primarily for the purpose of providing landing opportunities each day for the target landing site of White Sands Missile Range (WSMR). The constraints imposed on launch vehicle operations to achieve an integer orbit, the operational launch window constraints, and the difficulties associated with initial orbit adjustment to synchronize the ground track with the landing site suggests that alternate approaches be investigated for the RRS. Insertion of the RRS into a precise integer orbit (DRM-4) requires that the RRS have extremely accurate orbit determination capability and be able to make precise orbit adjustment and phasing burns. Once the RRS has achieved this precise integer orbit, then consideration is required for the approach to maintain this orbit while under the influence of orbital decay.

A preliminary investigation of the effect of atmospheric drag on a vehicle with an effective cross sectional area of 30 square feet and a mass of 100 slugs indicated that, for periods of increased atmosphere density, a 15 integer orbit at an inclination of 34 degrees would decay sufficiently in 25 days that orbit adjustment would be required to keep the nodal point of the ground track over the landing site. For periods of average solar activity, it was estimated that the orbital decay rate would decrease by a factor of three from that of the worst case. This would allow the drift of the nodal point to remain within the boundaries of the landing site if caution was taken to place the nodal crossing point near the western boundary of the landing site at the beginning of the mission and then let the decay rate vary the location of the nodal crossing point across the landing site for the duration of the mission. To accomplish this desired situation, it would require that extreme care and adjustment be made to the orbital parameters.

Another approach to establishing the desired goal of assuring a landing opportunity each day at the landing site is to use natural orbits and accept the availability of one landing opportunity each 24 hours. As the orbit regresses, periodic opportunities of two landing opportunities per 24 hours will exist for low inclination orbits whose inclinations match the upper limits of the landing site (DRM-1 and DRM-2). This approach minimizes the constraints on launch vehicle orbit insertion accuracies, precise orbital altitude conditions, ground track phasing, and orbit adjustments. Since the advantage of integer orbits is strictly for the benefit of landing opportunities and not because of the science or experiment objectives, it is felt that the use of natural orbits would be more desirable from an overall mission viewpoint.

For the case of high inclination orbits, such as DRM-3, the selection of near integer orbits would be desirable to maintain the orbital ground track near the landing site boundaries. Even water landing sites would benefit from the use of near integer orbits for high inclination missions. Such orbits would minimize the range of landing target points that the recovery vessel would have to cover over the period of a 60 day mission.

An advantage that water landing sites have over CONUS land landing sites is their location relative to the launch site. For a due east launch, the launch range can also serve as the landing site, thus minimizing the launch performance required to deliver the RRS to a low inclination orbit (DRM-5). This advantage can be used to propel the RRS into higher altitude orbits instead of being used to achieve orbital inclinations which match that of the landing site. Another advantage of water landing is the ability to move the target landing site instead of having to adjust the orbit to correspond with the nominal landing site.

3.6.2 Primary Landing Site Locations

The primary landing site for a land landing RRS is the White Sands Missile Range as shown in Figure 3.6.2-1. This range is approximately 40 miles from the east to west boundaries, and 100 miles from the north to south boundaries. Range extension areas are available above the northern boundaries but the terrain is not desirable for normal landing and recovery of the RRS. Specific areas of WSMR that should be considered for landing of the RRS include the area above the White Sands National Park which is bounded by the mountain range to the west and the range boundaries to the east. This area contains the majority of the smooth lake bed area and is the preferred target area. At the upper end of the range an area approximately 20 miles square identified as the 90 mile impact area also has terrain suitable for RRS landing operations.

The range is fully instrumented for missile operations and is supported by NASA and the armed services. The US Army and Navy have resources to assist in range operations. The cost of the use of the range itself is expected to be in the order of $50,000 for one day of use. This cost was based on the range support fee charged to Space Services Inc. this year to track the launch and recovery of the Starfire sounding rocket. Facilities are available for recovery and post-mission support. Ground vehicles are available for search and retrieval. Aircraft support can be provided from Holloman Air Force Base. The cost for the aircraft is usually charged on an hourly basis.

The primary landing site considered for a water landing RRS is the Eastern Test Range (ETR) whose NASA activities are primarily coordinated from Kennedy Space Center (KSC). The range covers the immediate coast line and extends over the Atlantic Ocean over a large range of inclinations. Support of RRS recovery could be accomplished with the shared usage of the recovery vessels which currently recover the Space Transportation System (STS) Solid Rocket Boosters. Aircraft support for range operations is available from nearby Patrick Air Force Base. Several facilities are available either on KSC proper or from the Cape Canaveral Air Force Station (CCAFS).

3.6.3 Contingency Landing Sites

Edwards Air Force Base (Figure 3.6.3-1) located in California appears to be the only reasonable sized alternative land landing site which has the necessary terrain and controlled air and land space for landing the RRS. This test range is approximately 5 miles wide by 14 miles long. It is primarily used to test aircraft and support STS landings. Support services for search and recovery as well as post recovery operations are available.

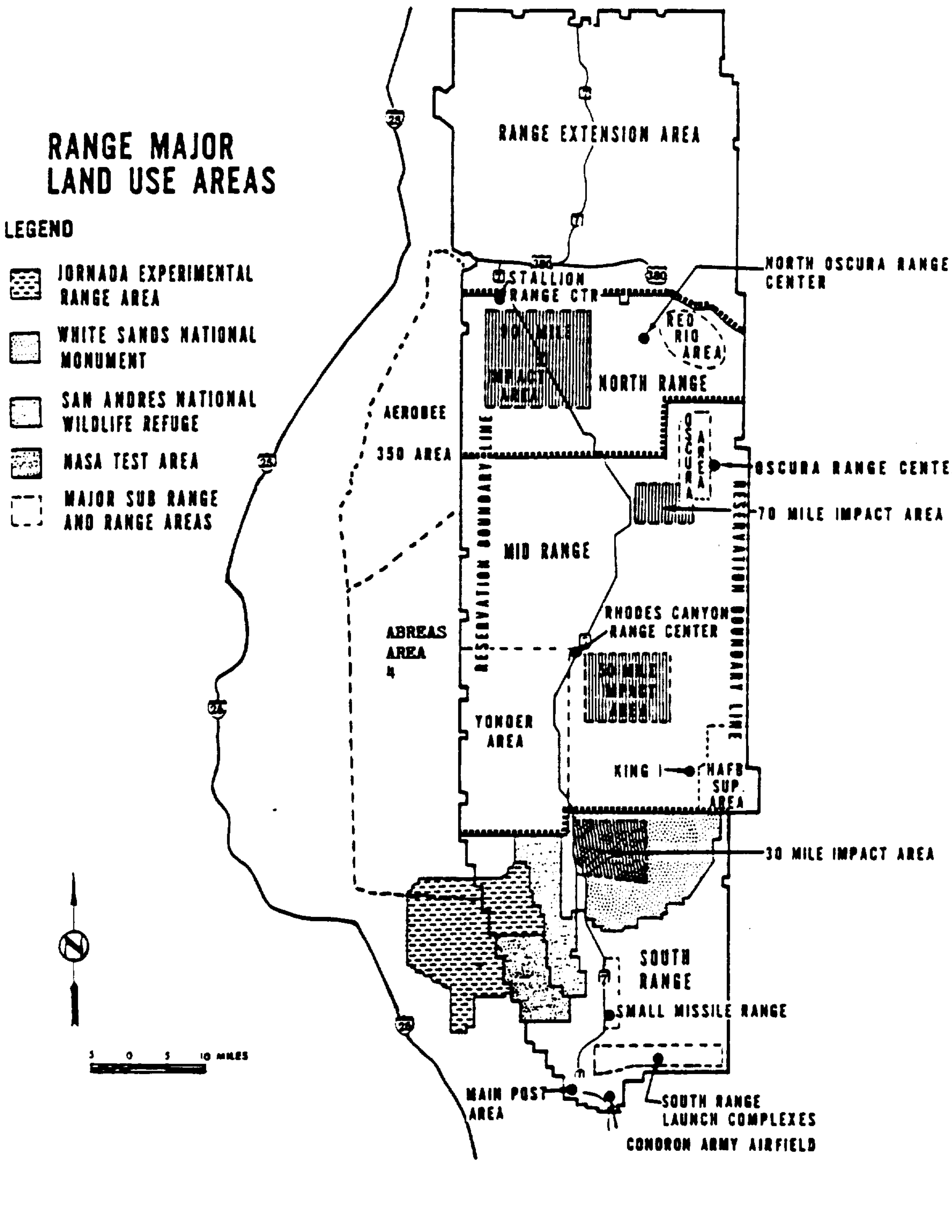


Figure 3.6.2-1. White Sands Missile Range Land Area

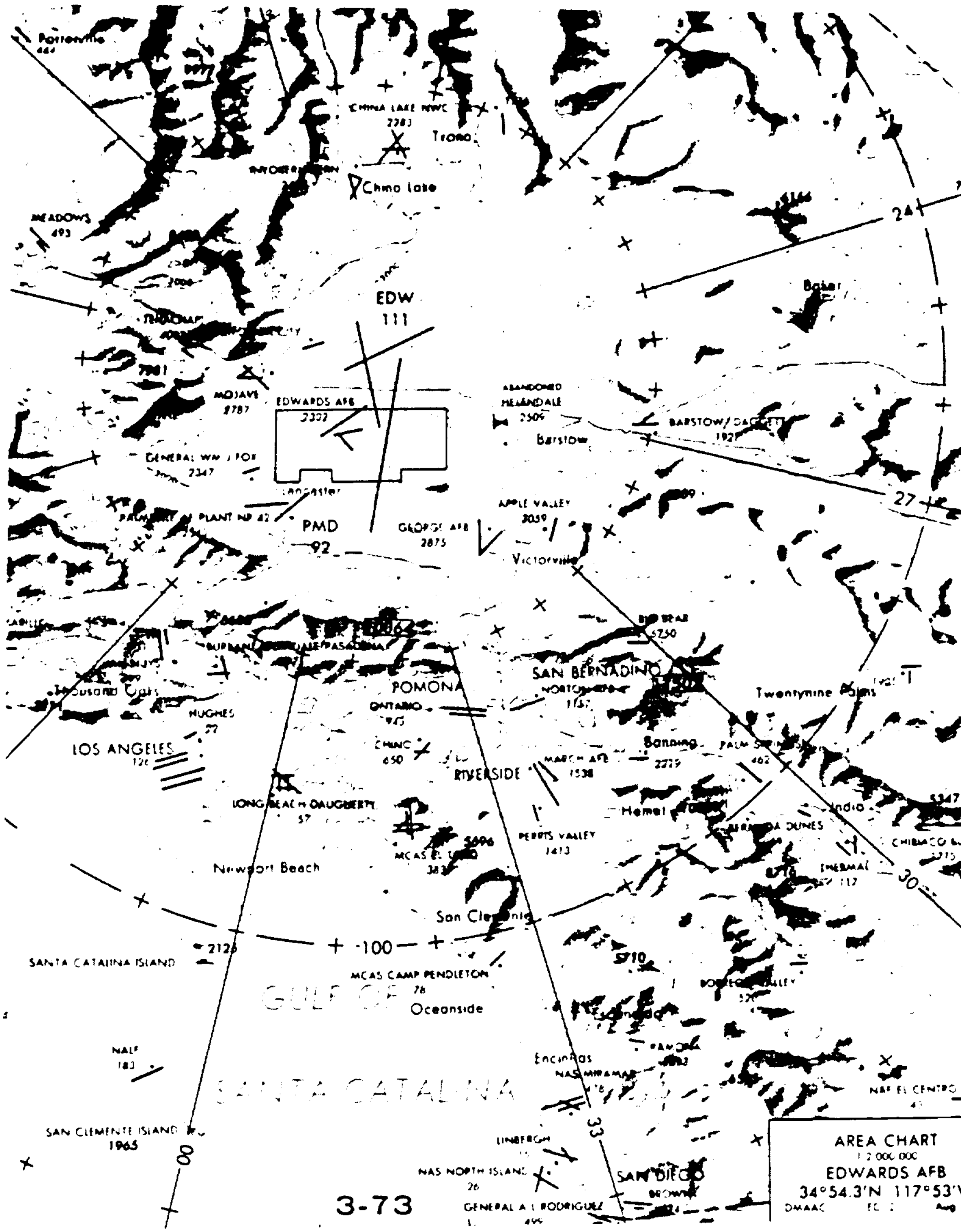
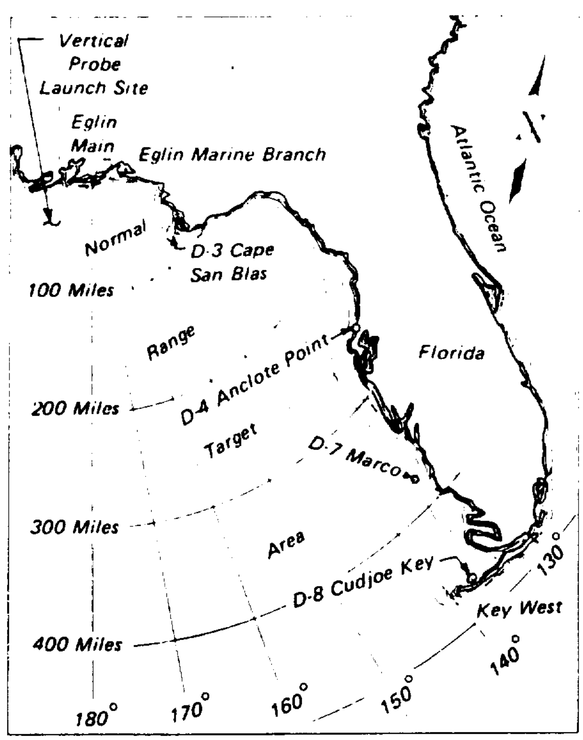


Figure 3.6.3-1. Edwards Air Force Base Land Area

Several landing sites are available to support a water landing RRS. These include the Eglin Gulf Test Range (Figure 3.6.3-2) situated on the norther gulf cost of Florida, the Gulf of Mexico between Texas and Florida, the Western Test Range (WTR) off the coast of California (Figure 3.6.3-3), the Wallops Flight Facility Launch Range (Figure 3.6.3-4), and the area near the Hawaiian Islands. The varied locations and support capabilities of each of these potential water landing sites offers multiple choices for RRS recovery.

3.6.4 Emergency Mission Termination

Emergency termination of a mission would require sufficient notification to clear the range for landing operations and adjustment of the orbital parameters to insure that the RRS would land within the boundaries of the land landing site. Depending upon the characteristics of the mission orbit and the capabilities of the RRS to perform orbit phasing maneuvers, the mission may be terminated from 24 hours to one after the need is identified. The minimum time is based on the need to clear the range and to arrange to have recovery support available to meet the PM recovery constraints. The upper end of the time spectrum is based on the estimated longest time required to perform phasing maneuver to align the orbital ground track with the landing site for a high inclination mission. Due to the long range WSMR user commitments, this time can be delayed much longer if prior range support operations are in progress.



Eglin Gulf Test Range, Florida

Figure 3.6.3-2. Eglin Gulf Test Range Area

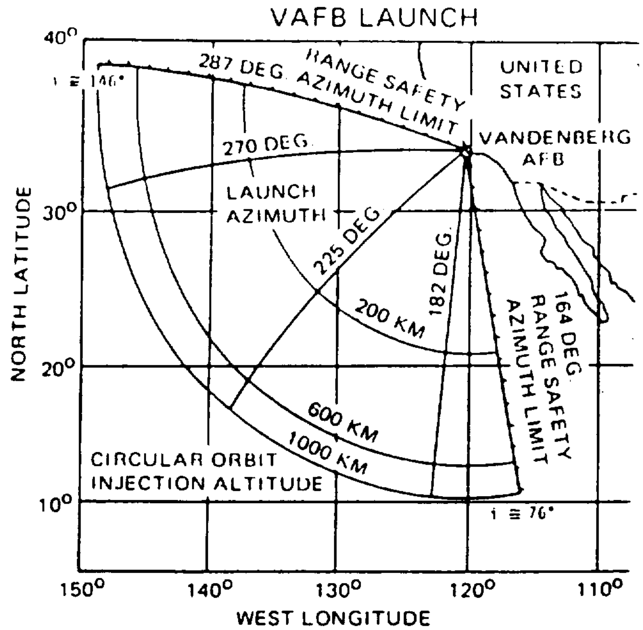


Figure 3.6.3-3. Western Test Range Area

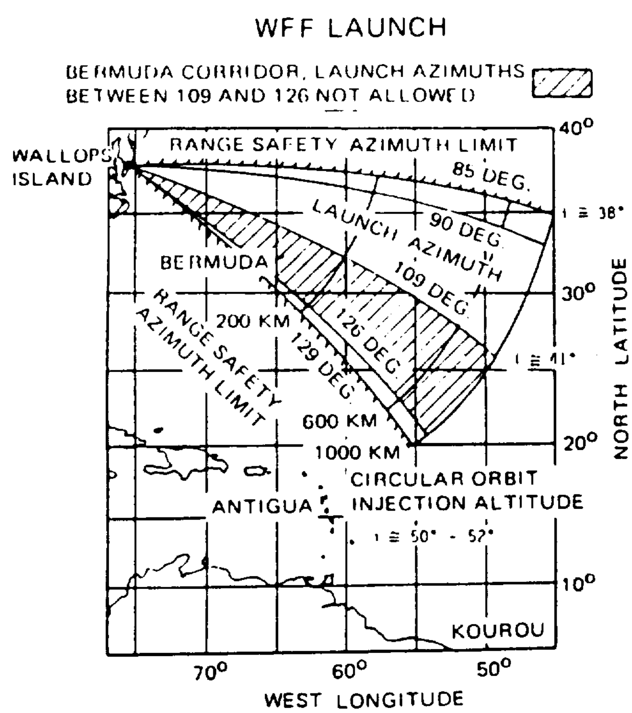


Figure 3.6.3-4. Wallops Flight Facility Launch Range Area

An alternative is to land the land-landing RRS in water in the event of a severe emergency and recover the RRS on a time available basis for the purpose of recovery of refurbishable high cost equipment. For this situation, it may be necessary to sacrifice experiments which may not survive the extended post-landing time delay.

For a water-landing RRS, it is also anticipated that the minimum time required to accomplish range support and recovery is in the order of 24 hours. Due to the nature of surface vessel operations, this time can be potentially delayed much longer if the vessels are involved with other operations such as a STS mission.

For high inclination missions, there exists two options; (1) change the orbit to correspond with a landing site close to the port of the recovery vessel, or (2) deploy the recovery vessel to the anticipated landing target point. From the point of operational efficiency, it would be preferable to place the RRS in a near integer orbit and let it naturally decay so the ground track has minimal precession during the life of the mission. Then it would be simple for the recovery vessel to be in the vicinity of the target point if it is within the 24 hour operating range of the vessel.

3.6.5 Reentry Debris

Reentry debris generated by a RRS targeting to a land landing site would constitute an unacceptable risk to public safety. This risk could be avoided by design to insure that all deorbited components remain intact through reentry. For the baseline vehicle, it would require the APM to remain attached to the basic vehicle and the heatshield be separated only if it is assured to land within the landing site range boundaries. The current RRS design keeps both of these components attached to the vehicle. This was not the case at the start of this study.

A water landing vehicle has a slightly greater flexibility insofar as the ground track crossing the target landing site can be placed over water. With proper choice of landing sites and orbital ground tracks, the dispersion range of any debris generated by uncontrolled entry of separated RRS components can be confined to the water landing range area.

3.6.6 Wind Effects

Design consideration for the effects of winds on a land landing RRS falls primarily into two areas; (1) high altitude winds which affect impact point dispersions and (2) surface winds which affect the horizontal velocity component at the time of impact. The basic design approach of using a small drogue to slow the descent velocity with minimum drift from high altitude winds provides a simple solution to the wind induced impact dispersion issue.

Surface winds at the time of landing can be accommodated by selecting mission schedules which avoid periods of high winds such as the spring of the year. Meteorological forecasts can also help optimize landing operations for periods of moderate winds once the vehicle is in orbit. As a design objective, the vehicle should be capable of landing under the surface wind conditions of mean wind speed for 1-hour exposure for WSMR as described in the "Terrestrial Environment (Climatic) Criteria Guidelines for use in Aerospace Development" (Reference 4).

A water landing RRS could use the same terminal landing technique as the proposed land landing RRS to avoid the problem of impact point dispersion. However, the problem of surface winds imposes difficulty in physical recovery of the RRS from the water. Surface winds generate seas which tend to persist even after the winds die down. As a consequence, recovery operations are usually constrained by sea states which are generated by winds. The statistical data presented in the Terrestrial Environment Criteria document provides information regarding seasonal and daily cycles of wind velocities. This information coupled with real-time meteorological forecasts are essential for mission planning.

3.6.7 Elevation Effects

The elevation of the landing site affects the design of the terminal landing system due to the density effects of the atmosphere. If the RRS is designed to land at WSMR, whose average altitude is approximately 4,000 feet, then the system must also allow landing at other contingency sites having different altitudes without exceeding the required impact parameters. This is especially critical with retro-rocket systems where ignition altitude and burn times are driven by descent velocity. For conventional parachutes and gliding parachutes, the WSMR altitude should represent the worst case altitude for landing considerations.

A water landing vehicle has the advantage that the final landing altitude is essentially the same. This limits the design considerations for terminal landing system design to factors other than altitude.

3.6.8 Visibility Effects

Visibility at WSMR is usually excellent except for periods of dust and rain storms. Typically, the desert environment provides good visibility for optical instruments year-round for 95% of the time, day and night. The mean visibility is 36 miles and cloud cover typically remains minimal. For the proposed RRS design, landing could be accomplished during the day or night since the vehicle does not require any visual sensors or operators to achieve landing. The recovery operations would, however, be aided with appropriate lighting systems to allow the manual procedures to be accomplished. If a gliding parachute is used with a remote operator, then daylight operations may be required for landing.

Visibility over water landing sites are not expected to be as good as those cited for WSMR. It is expected that some visibility obscuration will occur due to ground haze and be limited periodically by low altitude cloud cover. It is anticipated that for any water landing site that weather conditions would constrain operations for approximately 10% of the time per year. The actual landing of the RRS may occur in darkness, but the location and recovery of the vehicle would be hindered by darkness.

3.6.9 Terrain Effects

The terrain in the selected land landing sites is essentially either flat lake bed surface or smooth grassland. The nature of the surface may vary from hardpacked dirt to sandy soil. For most of the landing site, it can be considered that no surface obstructions exist and the surface is essentially uniform. However irregular objects and terrain may be located outside of the immediate landing area.

Water landing sites must consider the nature of the surface of the water when determining impact attenuation effects. Wave slopes which vary with sea state and the impact angle of the spacecraft with the water surface can cause different impact g loads. Vehicle design can use the cushioning effect of water penetration to reduce some of the impact loads. Operationally, the recovery of the RRS will be constrained by the sea state which varies with weather conditions.

3.6.10 Landing Site Facilities

Facilities to perform post-recovery inspection, safing, disassembly, and packaging are available at WSMR. There are additional facilities that can provide support for explosives handling, instrumentation testing, propellant handling, and general mechanical work. Facilities are available at Holloman AFB to provide meteorological support in the nature of forecasts, real-time data, and upper wind balloon launch data. All of these services and facilities are available for a reasonable fee.

Facilities available at KSC and CCAFS are similar in nature to those available at WSMR. However, some of the time critical support may have to be provided at the landing site by the recovery vessel for a water landing RRS. If this is the case, then limited capability exists aboard the recovery vessel to perform support functions for the RRS. Most of the support functions would have to be brought onboard or await accomplishment until the vessel returns to port and the RRS is transferred to facilities available at the launch site.

3.6.11 RRS Retrieval

Retrieval of the RRS and its Experiment Module can easily be managed by ground vehicles and helicopters at WSMR. The helicopters are expected to reach the RRS the quickest after landing and therefore would be use to carry the GSE and post-landing safety inspection equipment. Once it has been determined that the RRS is safe for post-landing operations, the GSE will be connected to the RRS. If the principal investigator prefers, the EM can be removed and returned separately from the basic vehicle to the site facilities for post mission analysis.

Physical recovery and return of the RRS to the landing site support facilities can be accomplished either with helicopters or with ground support vehicles. An estimated cost for the use of a H-53 helicopter is $1,300 per flight hour. Typically the aircraft use for a recovery mission requires from one to three hours and a backup aircraft should be considered. After the RRS has been returned to the site facility, any necessary deactivation procedures will be conducted and the vehicle prepared for return shipment to the refurbishment facility.

Retrieval operations for a water landing vehicle is expected to be primarily conducted from a surface recovery vessel like the SRB Recovery Vessel stationed at KSC. In this evaluation, it was assumed that shared use of the SRB Recovery Vessel would be available. In the event that these vessels cannot be used or available due to conflicts with the STS operations, the cost of providing adequate recovery vessels could considerably increase the cost of recovery operations. This vessel would normally depart port before the end of the mission and be on-station at the time of RRS landing. Normally the recovery vessel is located adjacent to the ground track and offset from the ground track by the normal cross-range dispersion distance. The cost of operating such a vessel is approximately $6,500 per day including the boat crew. For a typical mission, it is expected that the recovery vessel would be required for two days.

Aircraft support may be used to assist in the location of the RRS, and in the rapid transfer and return of the EM back to land based facilities. The typical cost for helicopter operations is the same as that cited for WSMR. Once the RRS is located and brought aboard the recovery vessel, the RRS will be inspected for safety hazards and connected to the GSE. It is anticipated that the conditions aboard the recovery vessel would not be suitable for post-landing experiment analysis purposes. After recovery, the vessel will return to port where the RRS will be unloaded and transferred to a land based facility for completion of the post-mission process. The unloading and dockside support of the transfer process is anticipated to cost $2,000. The post-recovery deactivation and preparation for shipment to the refurbishment facility is expected to proceed in a manner similar to that of the land landing RRS with some additional work to inhibit the degradation of the equipment and materials exposed to the salt water environment.

Another approach to RRS retrieval would be to recover the RRS by airborne capture. This approach would have the advantage of minimizing damage to the RRS due to land impact or water immersion. This technique has been operationally demonstrated by the U.S. Air Force for reentry packages weighing up to 4,000 pounds. The method used to perform the airborne capture is to suspend the recovery package from a large main parachute and a smaller engagement parachute. The engagement parachute is connected to the recovery package by a load line which supports the package after a helicopter engages the small parachute. At that time, the large main parachute is disconnected to prevent obstruction in the recovery process.

The helicopter is equipped with a pair of support poles extending below the body with an engagement loop connected between the poles as shown in Figure 3.6.11-1. Several hooks are located on the engagement loop to insure firm capture of the engagement parachute. Two helicopters are normally used in the operation and the approach started when the package descends below 10,000 feet in altitude. The pilot normally aims to pass above the engagement canopy by approximately 8 feet to allow the loop to snare the engagement parachute.

Once the parachute and recovery package is engaged, the helicopter returns to base and delivers the package to awaiting personnel and equipment. This method usually allows for three attempts for engagement during the descent and has a success rate of approximately 96%. The individual responsible for current operations has indicated that he would be willing to assess the feasibility of this approach to payload recovery for the RRS after a formal request has been made by NASA to the DoD.

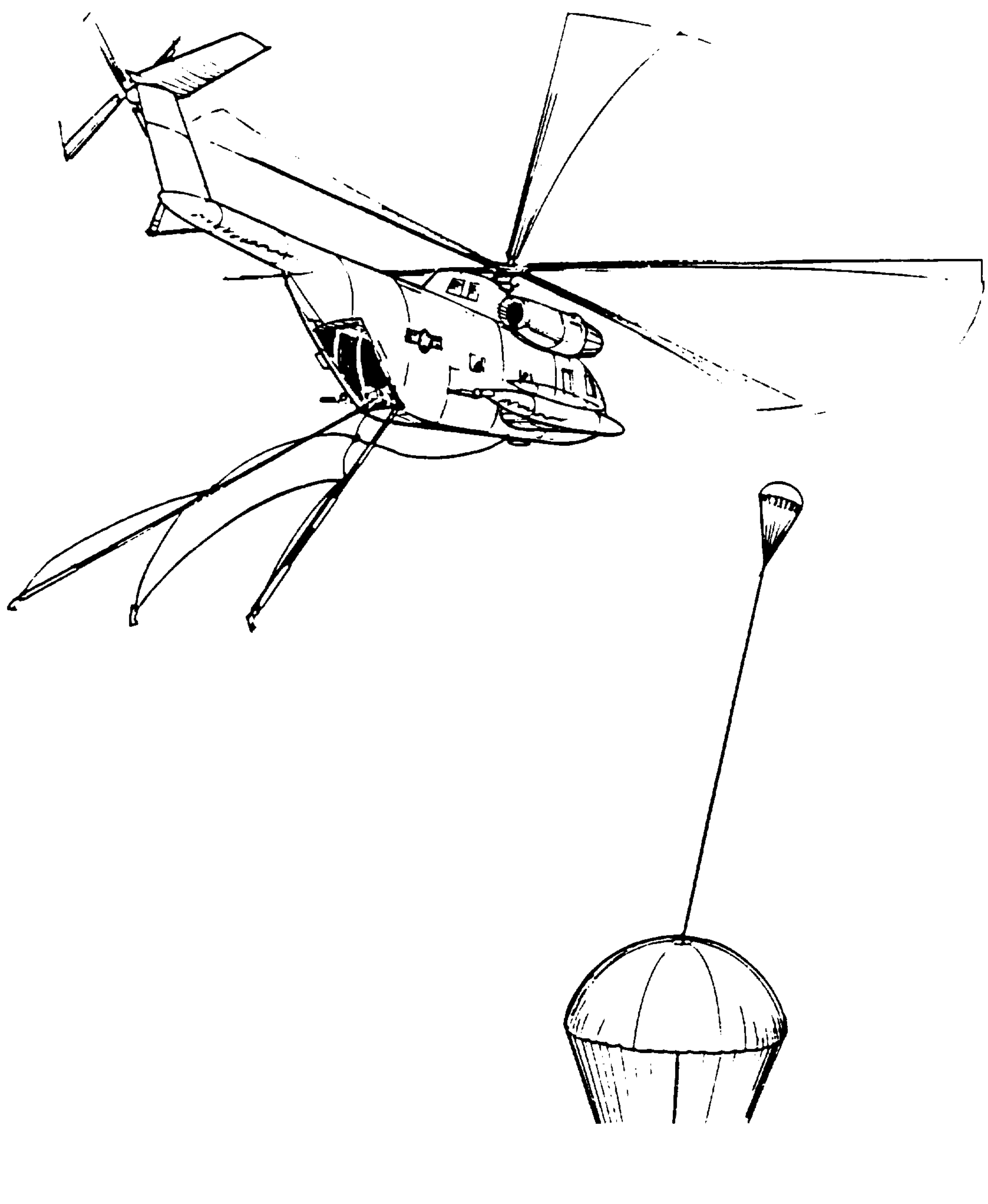


Figure 3.6.11-1. Trapeze/Helicopter Midair Retrieval System

3.7 Water versus Land Recovery Analysis

The selected trade parameters were assigned a subjective score based on a five point scale listed below:

1 - Very Poor
2 - Poor
3 - Fair
4 - Good
5 - Very Good

Each parameter was given a numerical score for the land landing concept and for the water landing concept based on the information discussed in Section 3.6 of this report. The scores listed in Table 3.7-1 represent a subjective evaluation of the operational complexity, vehicle design complexity, mission supportability, and operational cost of the parameter for both the land and water landing approach.

To evaluate the choice between a RRS design approaches, evaluation criteria were assigned for the goals of science objectives, design affordability, and operational simplicity. For the area of science objectives, the evaluation criteria selected were payload recovery response, mission reliability, and mission flexibility. For the goal of design affordability, the evaluation criteria were refurbishment costs and design constraints. For the goal of operational simplicity, the evaluation criteria were recovery operations complexity and landing opportunities. Each evaluation criteria was then assessed and assigned four factors from the list of parameters developed previously that were the most applicable to the evaluation criteria. This allowed the score for the evaluation criteria to be a composite sum of the scores of the individual parameters.

For each evaluation criteria, weights were assigned based on the relative importance of the evaluation criteria and goal category. The composite scores were then listed for each evaluation criteria for both the land and water RRS design approaches as shown in Table 3.7-2. These composite scores were then multiplied by the weight factor assigned to each criteria. Finally, the weighed sums were totaled for both approaches to arrive at a comparative score value for both approaches.

Table 3.7-1. RRS Land versus Water Trade Parameters

Parameter		Evaluation Rating Land	Evaluation Rating Water	Comments
Orbit Setup	(O)	3		- Orbit phasing adjustment required
			4	- Natural orbits acceptable
Primary Landing Site	(P)	3		- WSMR selected as primary landing site
			3	- ETR selected as primary landing site
Contingency Site	(C)	2		- Only Edwards AFB available as alternate landing site
			4	- Multiple landing sites available
Emergency Termination	(ET)	2		- Opportunity constrained by landing site
			3	- Opportunity constrained by recovery support availability
Debris	(D)	3		- Vehicle design must avoid debris generation
			4	- Landing sites allows for debris dispersal area
Wind	(W)	3		- Moderate winds acceptable for landing
			2	- Moderate winds detrimental to recovery operations
Elevation	(E)	3		- Design must consider site altitude
			5	- Uniform landing altitude
Visibility	(V)	4		- Good visibility available
			3	- Average visibility available
Terrain	(T)	4		- Smooth terrain available at landing sites
			2	- Sea state varies with weather conditions
Facilities	(F)	5		- Excellent facilities available
			3	- Shipboard facilities may be required
Retrieval & Access	(R)	5		- Excellent recovery capability available
			2	- Recovery capability must allow for variable conditions

Evaluation Rating Scale (1 to 5, 5 Best)

Table 3.7-2. RRS Landing Mode Evaluation

Criteria	Weight	Evaluation Rating		Weighed Score	
		Land	Water	Land	Water
Payload Recovery Response W,T,F,&R	20	17	9	340	180
Mission Reliability W,V,R,&ET	15	14	10	210	150
Mission Flexibility O,P,C,&W	5	11	13	55	65
Design Constraints O,C,D,&ET	20	10	15	200	300
Refurbishment Cost W,T,F,&R	20	17	9	340	180
Recovery Ops Cost P,C,F,&R	10	15	12	150	120
Landing Opportunities O,P,C,&ET	10	10	14	100	140
Total	100			1395	1135
Evaluation Sum Rating Scale (1 to 20, 20 Best)					

3.8 Conclusions and Recommendations

Based on the trade parameter and evaluation criteria used in this study, the land-landing configuration has an advantage over the water-landing configuration. This approach is a means of applying numerical scores to subjective estimates of relative advantages and disadvantages of different design approaches. Other items disclosed during the course of the study also led to findings and recommendations as follows:

- Perform detailed design assessment to assure that the RRS system design meets the safety requirements.
- Baseline land landing configuration with WSMR as the landing site.
- Initiate formal discussions with the WSMR Future Programs Team to assure access and support of the range for RRS operations.
- Use natural orbits for low inclination missions and perform any orbit adjustments for landing site targeting at the end of the mission.
- Use near-integer orbits for high inclination missions and allow orbital decay to precess the ground track over the landing site range.
- Perform early proof-of-concept tests of the terminal descent and landing system to assure that the design and operational approach are sound.
- Provide adequate design volume in the parachute storage area so that a conventional parachute can be used.

4.0 RRS LANDING SYSTEM TRADE STUDY

4.1 Purpose

The purpose of this study is to help select a landing system for the RRS using a comparison analysis applied to several different types of systems. The results are intended as a guide to select the optimum landing system in accordance with the requirements set in the RRS System Requirements Document (SRD). The major factors considered in the comparison analysis were:

- Safety
- Mission success
- Design complexity
- Operations
- Cost

The study focuses on the landing phase of the mission with the RRS landing occurring at White Sands Missile Range (WSMR).

4.1.1 Approach

Four reasonable options for landing systems were identified and first studied in some detail. These options are described in Section 4.3. The simplest, least expensive option that meets the requirements (Section 4.1.2) was sought. The selected option must be able to technically perform the mission, preferably be an off-the-shelf item, and minimize operational complexity and cost. The requirements specifically discourage new technology development unless significant benefits are associated with it.

In order to systematically compare the options with respect to each of the many factors involved, a comparison analysis method was used. Four options were selected and each was compared to the others for safety, mission success, design, operations, and cost factors that were relevant. This comparison process was used to narrow the options investigated to two competing design approaches. These two options were then studied in greater detail by obtaining information and development estimates from three potential parachute manufacturers on the competing design options. Based on these inputs, the results were evaluated and recommendations formed on the landing system design approach.

4.1.2 Applicable Requirements

The RRS SRD was reviewed for requirements which may have an impact on the choice of landing system for the RRS. The following requirements were considered directly applicable to this study:

> "3.1.7 Recovery Operations"
>
> The RRS shall be designed for safe operations during deorbit and surface recovery. The RRS shall be designed to deorbit so as to allow a near vertical descent from an altitude of at least 60,000 ft. with a 3 sigma probability of a footprint within a cross range dispersion of ±6 km and a down-range dispersion of ±30 km. The recovery system shall be designed to avoid a violation of the selected controlled recovery zone airspace.
>
> "3.2.1 Design Philosophy"
>
> A major objective of the RRS Project is to provide a reusable spacecraft that has low life cycle costs with minimum risk to the project and to public safety. To this end, the RRS design should be based on flight proven technologies to the maximum extent possible.

Existing flight hardware designs should be used whenever it is cost effective. Increased design margins should be used when consistent with systems constraints to minimize costs and require a minimum of refurbishment between missions. Redundancy will be provided where necessary for safety and mission success.

"3.2.4.2 Terminal Descent and Recovery"

The RRS shall have the capability to perform deorbit, reentry and terminal descent maneuvers with sufficient accuracy and control to enable rapid, efficient recovery of the PM at the designated recovery sight. Parachute deployment or other atmospheric braking device shall not cause more than 2 g's axial load. The "ground impact" shall not exceed 10 g's along any axis.

"3.2.5.1 PM Access - Post Recovery"

The RRS shall have the capability for providing physical access to the PM within two hours of ground touchdown. Provisions shall be made to provide thermal control and electrical power to the PM (via GSE) within TBD minutes of ground touchdown.

"3.2.9 Maintainability"

... It shall be an objective to satisfy GSE requirements with maximum use of off-the-shelf equipment and minimum new equipment design.

"3.2.10 Safety"

Applicable safety requirements.

"3.2.11 Reliability"

Applicable reliability requirements.

"3.2.12 Quality Assurance"

Applicable quality assurance requirements.

4.2 Assumptions

The following general and systems assumptions were used in this work.

4.2.1 General Assumptions

The following are assumptions which apply to the trade analysis:

- All mission requirements apply equally to all systems.
- Analysis is based on land landing only.
- Cost evaluation will be limited to DDT&E, hardware procurement, and recovery operations.

4.2.2 Systems Assumptions

The following are assumptions which apply to all systems in general:

- All reentry conditions up to drogue deployment are the same for all systems. This includes any ground impact point dispersions due to reentry maneuvers and upper atmosphere effects.
- All systems require the use of a drogue chute; however, due to dynamic pressure constraints, one or more drogues might be different in size.
- The final landing zone and terrain is the same for all systems.

4.3 Systems Options

A wide variety of options are possible for RRS landing system. On one end of the spectrum is a single large conventional chute and a structure capable of taking some impact load. On the other end of the systems investigated was an actively controlled gliding parachute system. Numerous possibilities lie in between. Since the requirements emphasize simplicity and minimum cost, simple parachute systems were emphasized.

The four landing systems chosen for this study are:

- Passive Attenuation - conventional chutes and passive shock attenuation
- Air Recovery - conventional chutes with air recovery
- Terminal Retrofire - small conventional chute with terminal retro package
- Gliding Parachute - gliding parachute with active guidance control

4.3.1 Passive Attenuation System Description

The passive attenuation system consists of two major subsystems, which are a conventional drogue/ parachute system and a landing shock attenuation system. The two systems are integrated to provide passive attenuation for the RRS to keep impact loads within the required bounds. The following is a list of system subassemblies :

- Drogue chute subassembly
- Main parachute subassembly
- Shock attenuation subassembly (air bag or crushable structure)
- Necessary timers, pyrotechnic disconnects and cutters.

Figure 4.3.1-1 shows the RRS descending under a conventional chute system with air bags inflated. The reliability of a single chute system (1 malfunction in 10,000 jumps for army personnel chutes) (Ref. 6) is sufficient to consider a drogue and single large parachute with no backup.

The impact shock attenuation for this system may be accomplished in several ways. In the past, recovery systems have used such methods as air bags, crushable material and mechanical shock absorbers. Also some degree of shock absorption is required around the spacecraft to prevent damage from tumbling after impact. Given preliminary findings on launch vehicle shroud envelopes it would be difficult to fit the RRS into any shroud should it require a larger diameter heat shield. Mechanical absorbers on deployable skids have been used in the past (or at least have been extensively researched) as a means for active shock attenuation. Early research on a development Gemini capsule showed it is possible to use this type of system on a reentry vehicle. However, the mechanical complexity of this system, and the weight and volume impact on the overall design of the RRS were sufficient reasons for discarding this option. Deployable air bags systems have also been extensively and successfully used in the past on missile drones, aircraft escape modules and spacecraft. Air bags have the advantage of providing light, low volume shock attenuation with large impact energy dissipation. A disadvantage of this system is the inflation system design. However, air bag design theory and practice is well understood and the hardware, manufacturing, and refurbishment costs for this type of system are low. Further analysis on these devices is needed.

4.3.2 Air Recovery System Description

The air recovery system consists of a drogue/parachute system and an airborne retrieval system consisting of an airplane or helicopter fit with an air snatch system. The difference between a parachute used in air recovery and a conventional one is that the air recovery chute is modified to accommodate a tow line to take the snatch and towing load from the airplane or helicopter. A pilot chute to be snatched must also be provided. The following is a list of system subassemblies :

- Drogue chute subassembly
- Engagement chute subassembly
- Main parachute subassembly
- Necessary timers, pyrotechnic disconnects and cutters
- Air snatch helicopter and crew (minimum of two required for multiple passes)

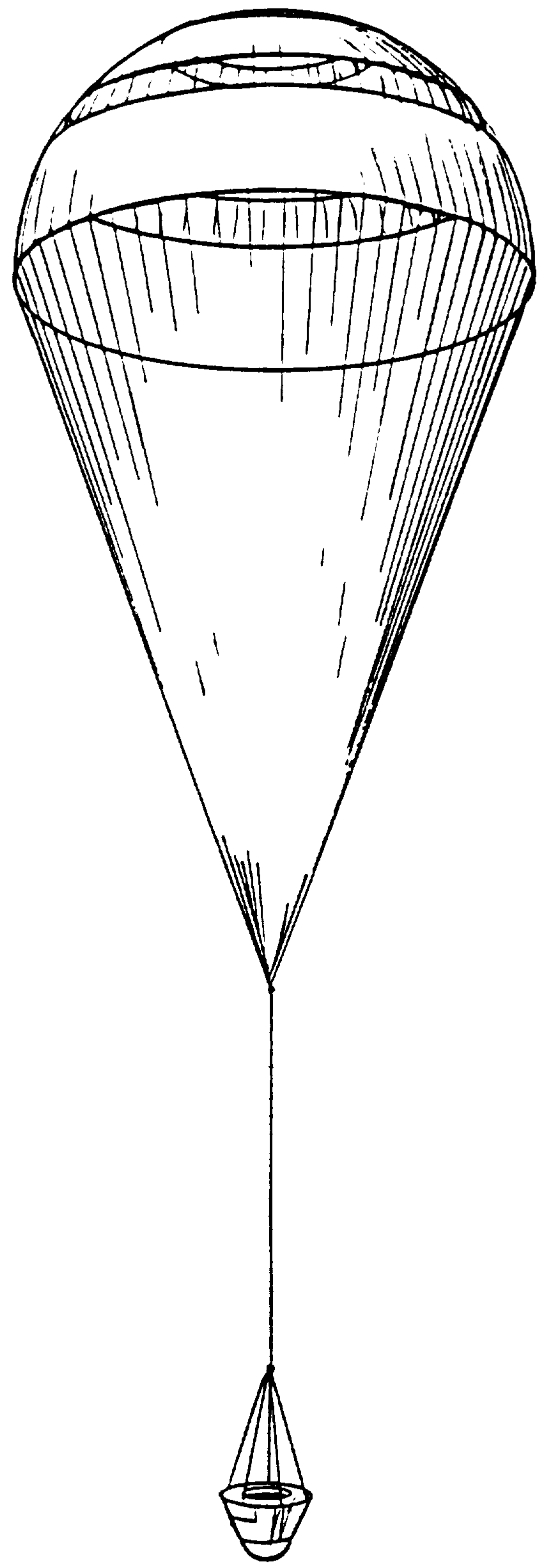


Figure 4.3.1-1. Passive Attenuation System

Figure 4.3.2-1 shows a HH-53 helicopter about to snare the engagement chute. The Air Force currently has two HH-53 helicopters rigged for air retrieval based at Hill Air Force Base that can retrieve up to 4,000 lbs. They are most often used for remotely piloted vehicle (RPV) retrieval (2,500 to 3,000 lb). The system snares the engagement chute. The main chute is then deflated and cut away. The helicopter tows the payload to a landing site bringing it inside for transportation. Recovery operations can start at around 10,000 ft. Two helicopters can make multiple passes at the vehicle, decreasing the chances of a miss.

In earlier work involving both helicopters and aircraft, the Air Force routinely recovered around 96% of the payloads (Ref. 6). Most of the losses were due to minor human errors, and for special work, much higher reliability on the order of 99.99% is said to be possible. However, to achieve this reliability, the maintenance of highly trained air crews with weekly exercises may be cost prohibitive to implement.

A significant advantage of an air snatch system is that it is compatible with recovery over water or over land. The helicopters are currently limited to within 30 miles of shore. More distant over water recovery will require a fixed wing aircraft recovery system. The Air Force C-130 based systems were discontinued in 1986. The Air Force will shortly dispose of the JC-130 snatch systems unless there is proven need to retain them. The technology is well understood if the system must be revived. However, the cost of maintaining crews and aircraft for long periods of time can be significant.

The Biosatellites (I, II, and III), launched in 1966, '67 and '69 had similar objectives and characteristics to the RRS. These systems used air retrieval over water and their experience can be some guide. Biosatellite I (940 lbs), a 3-day mission with a planned air retrieval off Hawaii, ended in failure when the retro-rocket failed to fire, leaving the satellite in orbit.

Biosatellite II (940 lbs) was successfully air-retrieved off Hawaii. Deorbit was initiated after 45 hours in orbit, 17 orbits earlier than planned because of communications difficulties and an approaching tropical storm in the recovery area. Air recovery by the USAF was successful and the recovery capsule was flown to Hickam AFB in Honolulu. A drogue chute was deployed at 80,000 ft and a main parachute at 10,000 ft. The recovery system also included radio transmitters and dye markers in case air recovery failed.

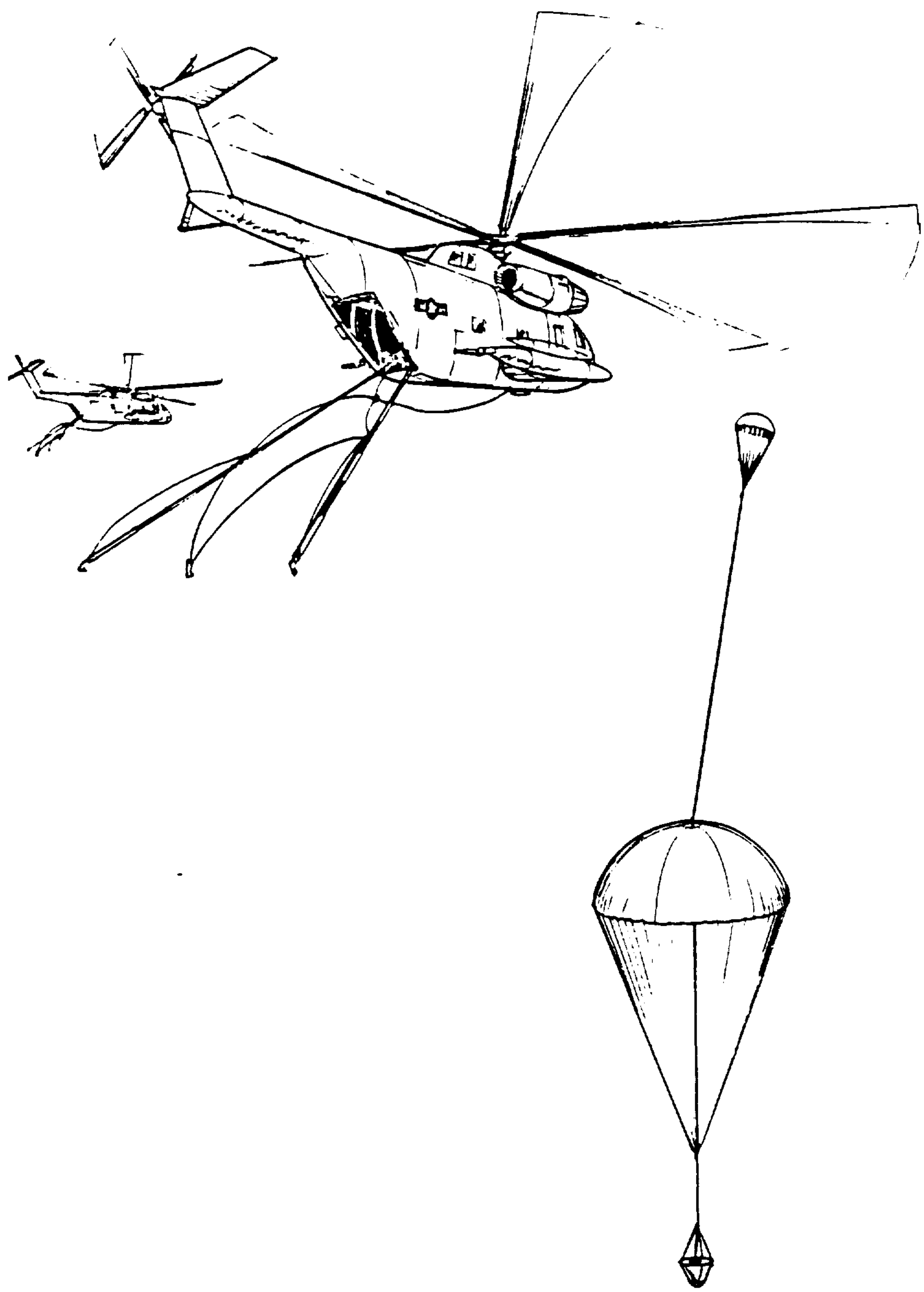


Figure 4.3.2-1. Air Recovery System (HH-53 Helicopters)

Biosatellite III (1,536 lbs) carried a monkey and was designed for 30 days in space. The vehicle was brought back after nine days when the monkey's condition deteriorated. The 19 square-foot drogue parachute deployed at 80,000 ft., seventeen minutes after retrofire. Ten seconds later, the reefed main chute deployed to 72 square feet, which then disreefed to open to 505 square feet. A mid-air retrieval was missed when the capsule was lost in the clouds and it splashed down 25 miles north of Kauai, Hawaii. A radio recovery beacon provided for backup sea-landing recovery enabled divers to locate and connect the capsule to a helicopter for a flight to a temporary laboratory at Hickam AFB.

An air-recovery system over land is attractive if the recovery can be made reliable enough to almost eliminate the chance of ground contact. It requires the minimum hardware on the spacecraft, particularly if no backup main chute is required. Several well trained and dedicated helicopter crews, two or more helicopters, a recovery area with consistent good weather, and time to wait in orbit for weather are all needed for high reliability air snatch. All are probably possible within the current RRS program plan. A conservative design might still include air bags or some other such device in the event the snatch was missed. The system therefore becomes the same as that described for the passive attenuation (section 4.3.1) with a chute system designed for air snatch. The air recovery then provides a probable quick and damageless capture, and some capability to change the recovery site (perhaps to over water or some other over land location) at the cost of helicopter crews, equipment, training, etc.

4.3.3 Terminal Retrofire System Description

The terminal retrofire system consists of a conventional drogue/parachute system and a terminal retrofire system. This retrofire system is comprised of a ground-sensing device and a solid rocket package that nullifies the vertical velocity component of the RRS to attenuate impact loads. The solid rocket package may be single or two stage and would be mounted along the main chute riser. A two stage system has the advantage of minimizing g loads by a sequenced, longer duration burn. An advantage of this system is that the conventional parachute system may be deployed at a very low altitude. This in turn decreases surface and winds aloft dispersions. Depending on the design of the retro-rocket system, the size of the main chute will vary between a full size chute canopy and a drogue chute size canopy, or the main chute may not be necessary altogether. The following is a list of system subassemblies :

- Drogue chute subassembly
- Main parachute subassembly

- Necessary timers, pyrotechnic disconnects and cutters.
- Retro rocket subassembly (TBD number of rocket motors + igniters + electronics)
- Ground sensing system subassembly (probe, radar, or optical ground sensing unit + electr.)

Figure 4.3.3-1 shows an RRS descending with a retro package on the riser.

Although there has been extensive research in this area of recovery systems, there are no active duty terminal retro-rocket recovery systems in the U.S. today. The Soviet Union uses such a system for manned spacecraft land landing however. The U.S. Army has been the primary sponsor of research on this subject in the West and has spent a sizable amount of money developing this system for payloads up to 35,000 lbs. (Ref. 7). Most of the problems associated with rocket motor performance and ground distance sensors have been worked out and the program has been reactivated to experiment with air drops of 50,000 + lbs. loads. The special handling of the motors in this system may be a potential drawback in the design and assembly of the RRS since it requires experienced pyrotechnic technicians to complete the task of handling, packing, checking, arming and refurbishing the motors safely and accurately.

4.3.4 Gliding Parachute System Description

The gliding parachute system consists of a deceleration drogue and main gliding parachute system. This system includes the necessary terminal guidance and control to bring the RRS to a predetermined landing area via automatic homing or active ground guidance. The basic advantage in using this system is that a certain degree of wind penetration and hence low wind dispersions are achieved. The landing zone may therefore become small. The following is a list of system subassemblies:

- Drogue chute subassembly
- Gliding parachute subassembly
- Necessary timers, pyrotechnic disconnects and cutters.
- Airborne flight control package
- Ground remote control unit

Figure 4.3.4-1 shows an RRS descending under a gliding chute. The control package is located on the riser in this concept.

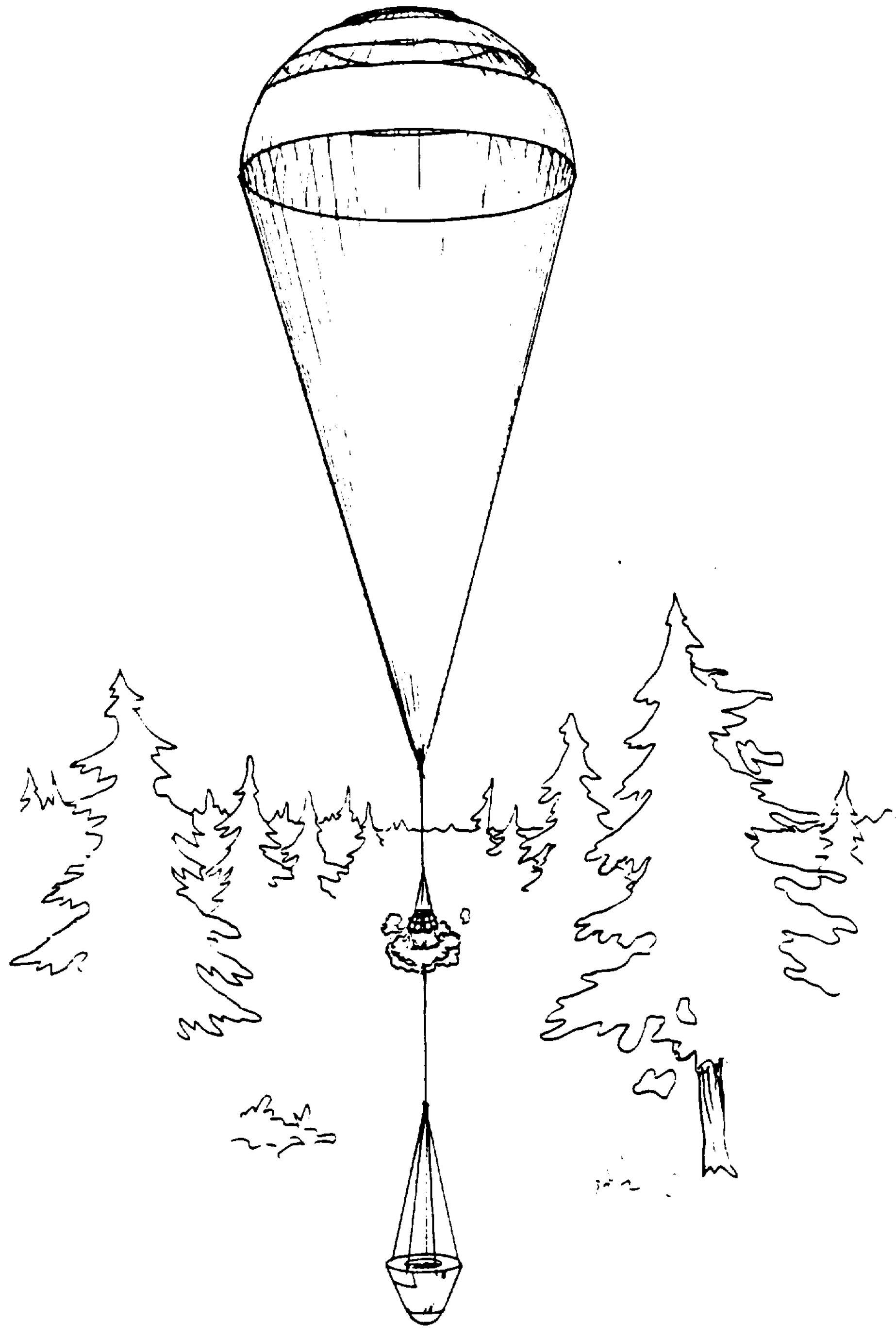


Figure 4.3.3-1. Terminal Retrofire System (Retro Package Firing)

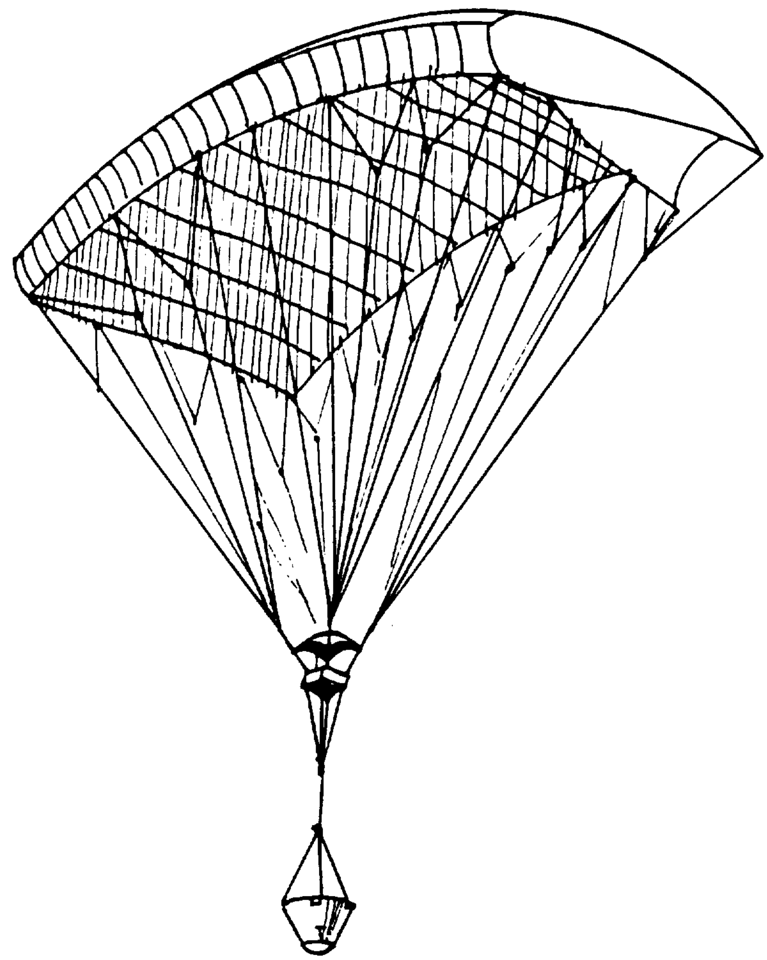


Figure 4.3.4-1. Gliding Parachute System

The system will probably require a person on the surface, remotely controlling the chute to flare at touchdown and assure the system is flying into the wind. Automatic flare is also a possibility. Given the right conditions, and a properly executed flare maneuver, the vertical and horizontal velocity components can be substantially reduced below those of a conventional chute. Failure cases may lead to downwind landings resulting in landings with the system's normal horizontal velocity plus that of the wind.

It is not clear if this system will require some kind of shock attenuation device for touchdown. Proposals include nets to fly into and large areas of sand or foam prepared for landing. If the gliding chute can null dispersions such that it can fly into a net or onto a prepared surface, shock attenuation or other protection may not be needed. Landing point dispersions due to factors prior to chute deployment and surface winds may not allow this, however.

A major difficulty with this system is that it is a more complex system which needs development for application to payloads in the weight class of the RRS. Such systems are under development at present, but recent test history has shown that the task will be difficult. The Marshall Space Flight Center (MSFC) is currently testing gliding chutes with 10,000 lb. payloads (Ref. 8). A successful deployment has recently been achieved and testing will soon commence on controlling the descent.

Practical gliding parachutes for 3,000 lb. payloads are not currently available operationally but are probably within reach. Any near-term program must count on parachute and control system development and test effort beyond what would be required for conventional parachutes at present.

4.4 Preliminary Comparison Analysis

The philosophy and criteria used in the initial screening is based on selecting safe, low cost, simple, proven designs with sufficient reliability to meet the required performance objectives stated in the requirements document. In other words, the landing system which will provide the required performance for the lowest cost is favored.

The comparison is subjective, but is based on the following logic. First, the system must be safe. Next, it must work without requiring extensive development. Given that a system works, cost must not be out of reason, therefore cost factors are important. A system that works and can be purchased may be adequate, even if it is difficult to operate. Many government systems witness this fact. However, simple operation is important if the system is to be practically reused. Lastly, the system should be reliable; in other words it should always work, therefore mission success probability and system reliability are factored in.

4.4.1 Evaluation Factors and Ratings

This section discusses each landing system option as it relates to various aspects of design considerations.

Safety Risk

A primary concern of the design choice is the potential safety risk to the RRS, the flight experiments, ground personnel, and the public. Each system was evaluated for factors which affect this important parameter.

Passive Attenuation: This system is very mature and its safety risks well known. Based on past experience, this system is given a score of good.

Air Recovery: The basic system element uses conventional parachutes and a demonstrated recovery technique that does not pose significant hazards to the user or the public. For these reasons, this system is given a score of good.

Terminal Retros: This system incorporates the use of retro-rockets to decrease the final impact velocity of the RRS. Included in the system are the rockets with the initiators and associated firing circuits. These elements pose potential known safety hazards to the personnel assembling and handling the system as well as to those recovering the system. For these reasons, this system was given a score of poor.

Gliding Parachute: Hardware involved in the gliding parachute system are similar to that of the conventional parachute system with the exception of the flight control unit. This system design does not pose any significant hazard to the operator and can avoid collision with obstacles. For these reasons the system was given a score of good.

Life Cycle Costs

The recovery operations costs should be considered as a contributor to the overall life cycle costs for any of these systems. The cost of the recovery operation will be in direct proportion to the people and support equipment involved. The other primary contributor to life cycle cost is the cost involved in refurbishing the landing system as well as the vehicle for reuse.

Passive Attenuation: This system does not require personnel at the landing site at the time of landing. The transport of equipment and personnel may be accomplished using ground transportation after RRS landing to within the time required for RM retrieval. The cost of operations can then be minimized by using conventional support equipment. This system received a score of very good.

Air Recovery: Keeping all personnel, aircraft and equipment flight ready is a costly task when compared to ground-only operations. It may be possible to borrow the air recovery system and crew from the Air Force, but for the number of flights discussed, this may be difficult. For this reason this system was given a score of poor.

Terminal Retros: The operations support for this system would be very similar to that of the passive attenuation system. However, the refurbishment costs of the system may be higher with the need to replace the retro-rockets and certain timing devices. Based on these reasons this system was given a score of fair.

Gliding Parachute: This system may require more ground support personnel than conventional parachute systems require. It does, however, have the distinct advantage of minimizing the potential damage to the vehicle upon landing. For these reasons, this system was given a score of very good.

Flight Proven Technology and Existing Hardware Design

One of the goals of the RRS design effort was to avoid the need for technology or design development in order to accomplish the mission objectives. One approach to accomplish this is to use existing designs and off-the-shelf hardware, where applicable, in order to keep development risk and costs to a minimum.

Passive Attenuation: Conventional parachutes systems and passive impact attenuation systems are well understood and have been demonstrated in the routine delivery of cargo whose weights far exceed that of the RRS. The maturity of the system design and technology gives this system a score of very good.

Air Recovery: Air recovery systems have been demonstrated by the Air Force for the recovery of payloads up to 4,000 pounds. The hardware and operations have been developed and demonstrated for several applications. The maturity of this system design approach is also given a score of very good.

Terminal Retro: Terminal retro systems have been developed as research programs in this country. However, no operational system is in active duty today. This approach to landing attenuation was investigated in some depth during the Gemini and Apollo program era to allow safe landing of manned spacecraft on land. Since operational designs do not exist today for application of this system to the RRS, it was given a score of fair.

Gliding Parachute: Gliding parachutes have been extensively used for personnel parachutes and have been developed to recover payloads slightly exceeding 2,000 pounds. Research is currently underway by NASA to develop gliding parachutes which will allow recovery of payloads in the 10,000 lb. range. Difficulties have been experienced in producing reliable performance in this weight range but it is expected that, with sufficient effort, a system could be designed to perform satisfactorily for the RRS. Since there is no operational system in the weight class of the RRS and that development effort is required, this system was given a score of fair.

Performance Success

Systems are scored based on the estimated probability of system performance success using past experience and existing similar systems as a guide. The ease with which a system can be backed up is also a factor, since overall mission success probability rather than the reliability of a single piece of hardware is being assessed.

Passive Attenuation: Conventional army personnel parachutes have a malfunction rate of 1 in 10,000. Extensive experience is also available on the use of conventional parachutes on the delivery of cargo and recovery of payloads. Given the success rate of conventional parachute systems and the passive nature of the shock attenuation system, this system was given a score of very good.

Air Recovery: Historical success rates for air recovery are in the range of 96%. Studies have shown that most of the failures are due to minor human errors. Aerial recovery success therefore hinges on the air crew and how well they have been trained to complete the mission successfully. The system can be easily backed up with additional helicopters and multiple passes, but weather and visibility can still be a problem. Then recovery becomes difficult. Based on all of these considerations, this system received a score of poor.

Terminal Retros: Terminal retro systems are not yet mature enough in this country to provide the numbers and information to suggest competition with conventional parachute systems. However, the tests that have been conducted promise high probability of success. Backup to some degree is possible with a two-stage system. This system was given a score of fair.

Gliding Parachute: All landing systems considered in this study are proven concepts; however, gliding parachutes of or above the RRS weight class are not currently in use, nor have they been fully developed as a system. Considerable experience is available with personnel class and small cargo delivery systems. The basic reliability of the existing systems is considered adequate for a single main parachute system design but not quite as good as that of conventional parachute systems. This system was given a score of good.

Landing Point Dispersions

Landing point dispersion control is an important factor to consider in the choice of a recovery system since it affects the payload access response time and the size of the landing site required to support the mission. All of the systems investigated were capable of meeting the basic requirement to landing within the dispersion ellipse defined in the RRS mission requirements.

Passive Attenuation: Conventional parachute systems are subject to wind drift after the main parachute is opened. The simplest way to minimize this effect is to lower the opening altitude to one which allows operational safety, yet reduces the time and effect of wind drift. By using an altitude of 10,000 feet for the opening altitude for the main parachute, it is expected that wind drift can be held to a minimum. This system was given a score of good.

Air Recovery: A system using helicopters to recover the RRS in the air would be very tolerant of any drift caused by winds. The main parachute would have to be deployed at an altitude that would allow the helicopters to start their interception process at 10,000 feet or slightly above. With a main parachute deployment altitude of approximately 20,000 feet, wind drift could be held to reasonable limits and the helicopters would have sufficient time to acquire the target and make multiple engagement passes. This system was also given a score of good.

Terminal Retro: The terminal retro system would minimize the effect of wind drift induced dispersions by rapidly descending through the atmosphere and performing retrofire prior to touchdown. By maintaining a higher rate of descent that with conventional parachutes, this system is relatively insensitive to wind drift. This system was also given a score of good.

Gliding Parachute: This system is the only system that is able to compensate for entry dispersions and wind drift. By using a gliding parachute, some of the entry dispersion errors could be canceled while the RRS is on its main parachute. It is also capable of performing very accurate landing and compensating for any surface winds that may be present at the time of landing. These performance advantages which exceed the requirements for dispersion control gives this system a score of very good.

Parachute Opening Loads

The requirement to maintain axial g loads to less than 2 g's during parachute deployment and atmospheric braking was felt to impose excessively restrictive limits on all of the parachute system options that were investigated. Reefing techniques and design approaches could be developed for each system approach at the expense of weight, cost, and system complexity. Since the entry and landing load requirements were significantly higher than parachute opening load requirements, it was felt that this requirement was inappropriate and should be reevaluated. All of the systems would have to make concessions to meet this requirement and therefore all were given a score of fair.

Ground Impact Attenuation

The reusable nature of the RRS and the survivability requirements for the experiments are the primary concern in this factor. These systems were judged on the basis of least possible damage due to impact.

Passive Attenuation: The compliance with impact load requirements will be the primary objective of the design of this system. Based on past experience with air bag attenuation systems it was given a score of good. Passive attenuation systems that will meet the 10 g requirement are not difficult to build.

Air Recovery: Impact loads are negligible for this system. The actual engagement loads are expected to be in the range of 2 g's. This merits a score of very good.

Terminal Retros: Impact loads are low for this system. The rocket motors are sized to the exact weight of the spacecraft, such that the total vertical velocity component is nullified. The horizontal velocity component (the surface wind) will remain. Based on this the system was given a score of good.

Gliding Parachute: Under the right circumstances, with a person on the ground controlling the precise landing location, the direction of the landing with respect to the wind, and nulling the vertical velocity with a flare, little or no damage would be expected. If it is possible to bring the vehicle into a net or prepared area on the ground no damage would occur. This system was given a score of very good.

Post Landing Access

Access to the PM within 2 hours is required to support the objectives of the RRS experiments. To meet this objective, each recovery system option was evaluated to determine their impact on post landing access time.

Passive Attenuation: A system using conventional parachutes and passive attenuation should be able to meet the time requirement for PM access. The only impact of the recovery system option choice would be to vary the time from landing until the time that the recovery personnel arrived at the RRS. It was estimated that the choice of recovery system would only cause a minor variable in the timeline of approximately 10 minutes. Since this system could meet the primary objective, it was given a score of good.

Air Recovery: Air recovery probably provides the fastest method of providing access to the PM. This approach eliminates several intermediate steps normally involved if a RRS is land on the surface of the earth and is then transported to the Post-Recovery facility. Since this system could significantly improve post landing access time it was given a score of very good.

Terminal Retro: A system using terminal retros would essentially go through the same steps as that of a system using conventional parachutes and passive attenuation. This system was also given a score of good since it met the basic requirements.

Gliding Parachute: A gliding parachute system is able to reduce the access time by accurately controlling the landing point and potentially reducing the distance to the Post-

Recovery facility. Both of these factors can improve the access time above that of a system using conventional parachutes. For these reasons, this system was given a score of very good.

GSE Access Time

GSE access may be desired shortly after the RRS has landed to provide power to the subsystems and to maintain thermal control of the experiments. The length of time from landing until GSE support will have a direct bearing upon vehicle weight, volume and consumables required to support the experiments.

Passive Attenuation: Access to a RRS using a conventional parachute is expected to occur immediately after the vehicle is checked for hazards and is safed. This system is not expected to cause any delays in the process and is therefore given a score of good.

Air Recovery: The air recovery system will not allow GSE support to the RRS until it is deposited on the ground. This means that the RRS must provide support for its systems until the RRS is transported to the Post-Recovery facility or the RRS must be lowered to the ground to allow GSE connection to the RRS. If the latter approach is used, the advantage of rapid access to the Post-Recovery facility may be negated. Due to the constraints posed by this recovery system option, it is given a score of fair.

Terminal Retro: GSE access time is essentially the same as that for the recovery system using a conventional parachute and passive attenuation. Safing of firing circuits for the retros could be accomplished by the same procedures used to safe pyrotechnics aboard the RRS. This system was given a score of good.

Gliding Parachute: GSE support would also follow vehicle landing and hazard safing. Some advantage of the proximity of the landing to the recovery personnel is apparent but the steps to provide GSE connection would be essentially the same as that used for the system using a conventional parachute and passive attenuation. This system was also given a score of good.

4.4.2 Evaluation Summary

The four landing system options were tabulated in Table 4.4-1 and evaluated for significant factors that would eliminate a system option.

4.4.3 Design Option Downselect

Comparison of the landing system options allowed the downselect of options from four to two. The air recovery system option was dropped due to the potential for high operational cost and limited mission success. To achieve mission success near the 99% range under good visibility conditions, it was estimated that the recovery crews would have to perform weekly training exercises to maintain the desired level of proficiency. This, in addition of assuring the availability of the helicopter flight crew, aircraft and specialized recovery equipment for the duration of the RRS Project life, was felt to be excessively costly from an operational viewpoint. In addition, the difficulty of overcoming the night visibility and all weather capability was considered an additional factor contributing to the decision to drop the air recovery system option.

The other landing system option that was dropped was the terminal retrofire system. This system was dropped due to the fact that it added an additional safety risk to the design of the vehicle and that some development effort would be required to make the system operational. This system requires the addition of the terminal retrorockets with associated timing and firing circuits. The terminal retrorocket system safety precautions necessary during assembly, testing, launch, and recovery could be avoided by the other three landing system options. Even though research development efforts have shown that this approach is a feasible method of recovery of payloads on land, some design and development effort is still necessary to produce a system that is acceptable for routine operational use for the duration of the RRS Project. Since the advantages of this landing system option were minor as compared to the use of a conventional parachute and passive attenuation, it was dropped from further investigation.

This left the gliding parachute system and the conventional parachutes system as the favored options for further design evaluation. These systems were then subjected to more detailed design, operation, and cost considerations to develop recommendations for landing system design.

Table 4.4-1. Preliminary Screening of Landing Systems

Screening Criteria	**Passive Attenuation**	**Air Recovery**	**Terminal Retrofire**	**Gliding Parachute**
Design Philosophy				
- Miminum Safety Risks	Good	Good	Poor	Good
- Low Life Cycle Costs	Very Good	Poor	Fair	Very Good
- Flight Proven Technology	Very Good	Very Good	Fair	Fair
- Existing Hardware Design	Very Good	Very Good	Fair	Fair
- Redundancy Necessary for Safety and Performance Success	Very Good	Poor	Fair	Good
Landing Point Dispersions				
- Dispersion Range	Good	Good	Good	Very Good
G Loads				
- Atmospheric Braking <2G	Fair	Fair	Fair	Fair
- Ground Impact <10G	Good	Very Good	Good	Very Good
Post-Landing Access				
- Access to PM in 2 hrs.	Good	Very Good	Good	Very Good
- GSE within TBD Minutes	Good	Fair	Good	Good

4.4.4 Conventional and Gliding Parachute Comparison

To perform comparison of the two landing systems, additional details were sought that would allow for a selection of the landing system design. The factor that were considered at this level were estimates of the recovery system weights, volumes, DDT&E costs, hardware costs, refurbishment costs, and test program complexity. To gain information on these factors, Mr. John Kiker personally contacted individuals at three parachute manufacturing firms. The firms contacted were Para-Flight Incorporated, Pioneer Aerospace Corp., and Irvin Industries, Inc. Table 4.4-2 lists the preliminary parachute system design considerations given to the manufacturers to provide them a basis for their proposed design estimates. Para-Flight responded by providing an estimate for a gliding parachute that would be capable of landing the RRS with automatic homing and ground control of the landing. Pioneer Aerospace provided information on parachute design estimates for both a conventional and a gliding parachute design. The gliding parachute design was limited to the parachute itself and did not contain information regarding the control system or its development. Irvin responded with a design estimate on a conventional parachute design that would be able to land the RRS. A summary of the information provided by the various manufacturers is presented in Table 4.4-3.

From the information provided by the various manufacturers, Table 4.4-4 with subjective scores for landing system comparison of operations, system development, design, and cost factors was developed. Characteristics of a typical conventional parachutes system (Table 4.4-5) and a gliding parachute system (Table 4.4-6) are listed to illustrate each of these systems.

4.5 Conclusions and Recommendations

Evaluation of the landing system design options narrowed the choice down to either a conventional parachute system with passive attenuation or an actively controlled gliding parachute. The conventional parachute system will meet the requirements of the RRS at a minimum of risk for design and cost. It is based on a mature technology where the design parameters are well understood. The gliding parachute system potentially reduces vertical impact loads and offers some operational performance advantages in terms of landing accuracy and recovery times. It also has a minor advantage in terms of hardware weight and volume. These advantages are countered by higher development risks, development costs, and hardware costs, as well as test program complexity.

Table 4.4-2. RRS Parachute System Design Considerations

RRS CHARACTERISTICS	
Vehicle Mass	3000 lbs.
Operational Life	10 years
No. of Reuses	10
Landing Altitude	4000 ft. AMSL
CONVENTIONAL PARACHUTE	
DROGUE	
Deployment Method	Mortar
Drogue Deployment Altitude	30,000 ft.
Activation Method	Baroswitch
Design Velocity	$< M = 1$
Type	Conical Ribbon
Number	1
MAIN	
Deployment Method	Pilot Extraction
Main Deployment Altitude	10,000 ft.
Activation Method	Baroswitch
Design Velocity	150 KEAS
Type	Ringsail
Number	1
Rate of Descent @ 4,000 ft.	20 fps
GLIDING PARACHUTE	
DROGUE (Same as Conventional Parachute)	
MAIN	
Deployment Method	Pilot Chute Extraction
Deployment Altitude	10,000 to 20,000 ft.
Activation Method	Baroswitch or Ground Command
Design Velocity	(TBD)
Type	High Glide Ratio Parachute
Glide Ratio	> 2.0
Number	1
Rate of Descent @ 4,000 ft.	10 to 25 fps
Vertical Touchdown Velocity	< 10 fps
Guidance	Automatic Homing and Ground Control
Landing Flare Control	Manual Ground Control
INFORMATION REQUESTED FROM MANUFACTURER FOR BOTH DESIGNS	
Estimated System Weight	
Estimated System Volume	
Estimated DDT&E Costs and Time	
Estimated Hardware Cost	
Estimated Hardware Flight-to-Flight Refurbishment and Replacement Costs	
Anticipated Test Program Duration and Number of Drops to Qualify the System	

Table 4.4-3. Parachute Industry Source Data

Manufacturer	Representative	Gliding Parachute		Conventional Parachute	
Para-Flight, Inc.	Troy Loney	X			
Pioneer Aerospace Corp.	William Everett		X	X	
Irvin Industries, Inc.	Phil Delurgio				X
Estimated System Weight		135 lbs.	90 lbs.**	130 lbs.	160.6 lbs.
Estimated System Volume		2.95 $ft.^3$	2.6 $ft.^3$	3.7 $ft.^3$	3.14 $ft.^3$
Estimated DDT&E Costs		\$1.2M-\$1.4M	\$1.16M	\$.78M	\$1.28M
Estimated DDT&E Time		-	2 years	1.5 years	-
Estimated Hardware Cost		\$100,000	\$38,000	\$17,500	\$40,000
Estimated Refurbishment Cost		\$15,000	\$8,500	\$5,800	-
Anticipated Test Program		1 year	1 year	0.5 year	-
Number of Drops to Qualify System		25-30	15	10	10

** Cost, weight, and volume do not include guidance, navigation, and control equipment, on-board sensing, steering actuators, or power source.

Table 4.4-4. Landing System Comparison

Factor	Evaluation Criteria	Conventional Parachute	Score	Gliding Parachute	Score
Operations	Dispersion Control	• Meets RRS reqmts.	4	• Better than reqmts.	5
	Impact Attenuation <10G	• Meets requirements	4	• Better than reqmts.	5
	Weather/Lighting	• Meets requirements	4	• Meets requirements	4
System Development	Demonstrated Technology	• 1.5 year development • 10 drop tests	5	• 2 year development • 25-30 drop tests	3
Design	System Weight	• 160 lbs.	3	• 135 lbs.	4
	System Volume	• 3.7 ft.	3	• 2.95 ft.	4
	Hardware complexity	• Passive systems	5	• Active control systems	4
Cost	DDT&E	• $.78M - $1.28M 1 year	5	• $1.4M - 2 years	4
	Hardware	• $17,500 - $40,000	5	• $100,000	4
	Refurbishment	• $5,800	5	• $15,000	4
		Conventional	43	Gliding	41

Table 4.4-5. Conventional Parachute System Characteristics

- Parachute Design
  - Drogue
    - 7.3 Foot Ribbon Chute
    - Single Stage Reefing
    - 25,000 Foot Deployment Altitude
    - Mortar Deployment
  - Main
    - 112.4 Foot Ringsail Chute
    - Single Stage Reefing
    - 10,000 Foot Deployment Altitude
    - Drogue Release Deployment
    - Automatic Disconnect at Landing
  - Parachute System Weight
    - 160 Pounds
  - Impact Attenuation
    - Airbags or
    - Crushable Honeycomb

Table 4.4-6. Gliding Parachute System Characteristics

- Drogue
  - 13 Foot Ribbon Chute
  - Single Stage Reefing
  - 25,000 Foot Deployment Altitude
  - Mortar Deployed Drogue
- Main
  - 1,100 Square Feet Platform Area Ram-Air High-Glide Parachute
  - Reefed Deployment of Main Parachute
  - 20,000 Foot Deployment Altitude
  - Dynamic Pressure <50 psf
  - Main Deployment by Release of Drogue
  - Glide Ratio >2.5
  - Automatic Homing and Ground Control of Guidance
  - Manual Control of Flair Maneuver
  - Automatic Disconnect at Landing
- Parachute System Weight
  - 135 Pounds
- Passive Impact Attenuation
  - Crushable Honeycomb

It is recommended to proceed with the RRS design definition process using the conventional parachute system with passive attenuation as the baseline landing system. This recommendation is made on the basis that it provides a system which meets the RRS requirements with the most mature technology at the least risk to performance, cost, and schedule impacts. If it is desired to incorporate gliding parachutes into the design for their performance advantages after their risks are understood better, then they could be accommodated within the weight and volume allotments provided for conventional parachutes.

5.0 RRS PAYLOAD RECOVERY AND EXPERIMENT ACCESS ANALYSIS

5.1 Purpose

The purpose of this task is to assess the feasibility of developing an operational timeline which satisfies the 120 minute experiment access objective. Since access time to the experiment is a critical science requirement, a conceptual timeline of activities starting from RRS landing until experiment removal will be developed to serve as a reference for the various design option trades. Additional objectives of this task were to identify design options which could influence each step of the timeline and to identify facilities, RRS ground support personnel, GSE, and vehicles required to support the operations. With appropriate feedback from the subsystem design groups, an overall assessment of each design option can be weighed to arrive at the best design solutions that meet the science, safety and cost objectives.

5.2 Approach

The approach taken in this study was to start with the RRS configuration as presented in the Interim Status Review. From this description of the spacecraft, a timeline of activities describing the postlanding activities leading to experiment module access was developed including a listing of the necessary facility support, manpower, ground support equipment, and vehicles necessary to accomplish the activity. To determine the best operational approach to minimize experiment access time, several operational procedures were evaluated to assess access time, operational support and design factors influencing each approach. After the reference operational procedure had been selected and developed, specific spacecraft design options were identified to assess their impacts to access time, subsystem design impacts, ground support requirements, safety, and costs. Coordination with the affected subsystem design group will allow the spacecraft designers to provide their assessment of the impact of the design option to their respective subsystems. This feedback will provide a coordinated product between the recovery operations and the spacecraft design groups which reflect the best option for the RRS experiment access needs.

5.3 Applicable Requirements

The RRS SRD was reviewed for requirements which may have an impact on this trade study. The following requirements were considered directly applicable to this study.

"3.1.7 Recovery Operations"

The RRS shall be designed for safe operations during deorbit and surface recovery. The RRS shall be designed to deorbit so as to allow a near-vertical descent from an altitude of at least 60,000 ft. with a 3 sigma probability of a footprint within a crossrange dispersion of ±6km and a downrange dispersion of ±30km. The recovery system shall be designed to avoid a violation of the selected controlled recovery zone airspace.

"3.2.5.1 PM Access - Post Recovery"

The RRS shall have the capability for providing physical access to the PM within two hours of ground touchdown. Provisions shall be made to provide thermal control and electrical power to the PM (via Ground Support Equipment) within TBD minutes of ground touchdown.

"3.2.10 Safety Requirements"

The safety of the RRS, the flight experiment, ground personnel, the public, and the prevention of damage to property, and ground and flight property ground and flight hardware shall be of prime consideration in the total system design. The design tradeoff studies shall include evaluation of the measures to be employed to prevent both inadvertent operations and the occurrence of hazardous conditions during all phases of development, testing, operations, and refurbishment. The design evaluation shall include the impact on other equipment, payloads, personnel, and public safety as a result of malfunctions, failures, and abnormal spacecraft performance.

"3.3.5.5 Recovery Phase"

The RRS Thermal Control System shall be designed to minimize the reentry heat soak into the internal cavity of the vehicle and to minimize the increased RRS PM temperature. The design shall allow thermal control via GSE to be applied to the PM within TBD minutes of ground touchdown.

"4.2.4.2 Post - Recovery Timeline"

The RM design shall satisfy a Post-Recovery timeline which includes: connection of ground cooling and power by impact plus TBD minutes; delivery of the RRS to the Post-Recovery Facility by impact plus TBD minutes; and removal of the flight animals by 2 hours after impact.

"4.7.3.1 Post Flight Environmental Data"

The RM shall record environment measurements for analysis after recovery. The measurements described in this section will only be used after recovery and need not be telemetered during flight. A detailed list is included in Table 4.7.3.1.

"4.7.3.2 Post Flight Image Data"

The RM shall provide the complete record of flight images after recovery.

5.4 General Guidelines

The following general guidelines were used in this analysis:

- Baseline vehicle configuration is that described in the Reusable Reentry Satellite (RRS) System Design Study status review dated November 28, 1989.
- The landing system may consist of a conventional or gliding parachute.
- The Post-Recovery Facility will be located at the NASA White Sands Test Facility located on the White Sands Missile Range (WSMR).
- The maximum distance between the Reusable Reentry Vehicle (RRV) landing point and the Post-Recovery facility is determined by orbital ground tracks which cross the extremes of the WSMR.
- Both daytime and nighttime landings must be supported by recovery operations.
- Hazardous systems must be placed in a safe mode after landing.

5.5 System and Operation Assumptions

The following system and operation assumptions were used in this analysis:

- All appropriate landing and recovery support personnel will be at their designated stations at the time of RRV landing.
- Global Positioning System (GPS) data may be augmented by electronic and visual location aids to assist the RRV recovery personnel in determining RRV location during landing.
- Mobile Ground Support Equipment (GSE) will be available to erect the RRV and remove the Payload Module (PM) from the spacecraft.
- Propellant reserves and residuals are retained onboard the RRV at landing.
- Hazard safety inspection activities at the landing point will include propellant vapor detection, thermal hazard assessment, visual inspection and pyro circuit safing verification.

- Electrical power for the PM Environmental Control Life Support System (ECLSS) will be provided by the spacecraft after landing until the ground support personnel can connect GSE to provide ground power.

- Access to the PM requires removal of the recovery system container.

- Any special tools or GSE required for PM removal will be available as RRV unique GSE.

- A Ground Control Experiment Module (GCEM) Support Cart specifically designed for post-landing support of the PM will be available if required. The GCEM Support Cart will provide the necessary GSE support for PM services as specified in the system design requirements. The Support Cart has a wheeled carriage which allows it to be towed by another vehicle.

- Power, data, and fluid interfaces between the RRV and the PM will be designed with rapid connection and disconnection in mind.

- The launch support interfaces are available to provide post-landing thermal control to the PM with GSE after landing.

- The cooling loop reservoir has sufficient thermal storage capacity to maintain PM environmental temperature requirement during vehicle ascent, descent, and recovery. Sufficient thermal storage capability will exist to maintain the temperature of the Experiment Module (EM) within required limits for three hours after Astromast retraction prior to deorbit.

- Method of structural attachment of the PM to the RRV structure is TBD.

- Attachment points for lifting and restraining the RRV and its modules by GSE and/or cranes and helicopters will be built into the basic structure.

- Access to the experiment module within the PM pressure vessel is assumed to be through a pressure vessel cover retained by a quickly detachable device.

5.6 Post-landing Recovery Operation Options

Three basic payload recovery and access options were selected to evaluate recovery operations and RRV design options. These recovery operation options are as follows:

1. Helicopter Return of RRV and EM Access in Post-Recovery Facility.

2. Helicopter Return of RRV with PM Removal on Facility Apron and EM Access in Post-Recovery Facility.

3. PM Removal at Landing Site with Helicopter Transfer of PM and EM Access in Post-Recovery Facility.

A fourth option considered the removal of the EM at the landing site to reduce the access time but was excluded due to exposure of the experiment to the uncontrolled ambient environment of the landing site and the potential costs and complexity required to avoid compromising the scientific objectives.

The initial evaluation assumed a timeline for the postlanding activities which started from the time of landing of the RRS at a point which is approximately 75 miles from the NASA Test Facility area. A map of the WSMR is shown in Figure 5.6-1 with locations of various facilities and landing zones illustrated. The 75 mile distance represents a landing of the RRV in the 90 mile WSMR impact area in the North Range which is approximately 75 miles from the NASA facility. Since the ground track is controlled by orbital mechanics and the RRV is a ballistic vehicle, the end-of-mission landing point can end at the 90 mile impact area. For a ballistic entry vehicle crossing WSMR on a low inclination non-integer orbit, the predicted landing point may be anywhere on the range with a suitable surface. High inclination missions using near integer orbits may also require the use of the 90 mile WSMR impact area for ground tracks crossing the western portion of the range. Much of the rest of the western half of WSMR is either mountainous or occupied by facilities and areas not suitable for RRV landings.

Later evaluation of transportation times indicated that too much time was required to travel the 75 miles carrying an external load. Therefore, since Holloman AFB was more centrally located, it was assumed as the location of the Post-Recovery facility along with a restriction that landing sites be within 40 miles of the facility. This allowed a more reasonable transport time of 40 minutes. End-of-mission target points can be as close as 10 miles to the Post-Recovery facility if the orbital ground track happens to cross that point on the day of mission termination. This, however, does not mean that we can always choose to terminate the mission on that orbit just to suit access time desires. Mission operations do have some degree of flexibility in selecting which orbital path crossing WSMR should be used for the end-of-mission. Other factors such as weather and experiment objectives may also influence the choice of the specific mission termination orbit.

The timeline continues through all of the activities related to RRV recovery until the RRV is delivered to the Post-Recovery facility and access is gained to the Experiment Module (EM).

The times specified for each step of the post-landing activity represents an estimate of the range of time required which is dependent upon the subsystem design option, transportation method, and operational procedure selected as well as range environmental conditions at the time of landing. The minimum time is the estimate for the operation when all activities are performed according to plan and the RRS design reflects optimum consideration for recovery operations. The time increment for operational uncertainty is the additional time that may be required if planned

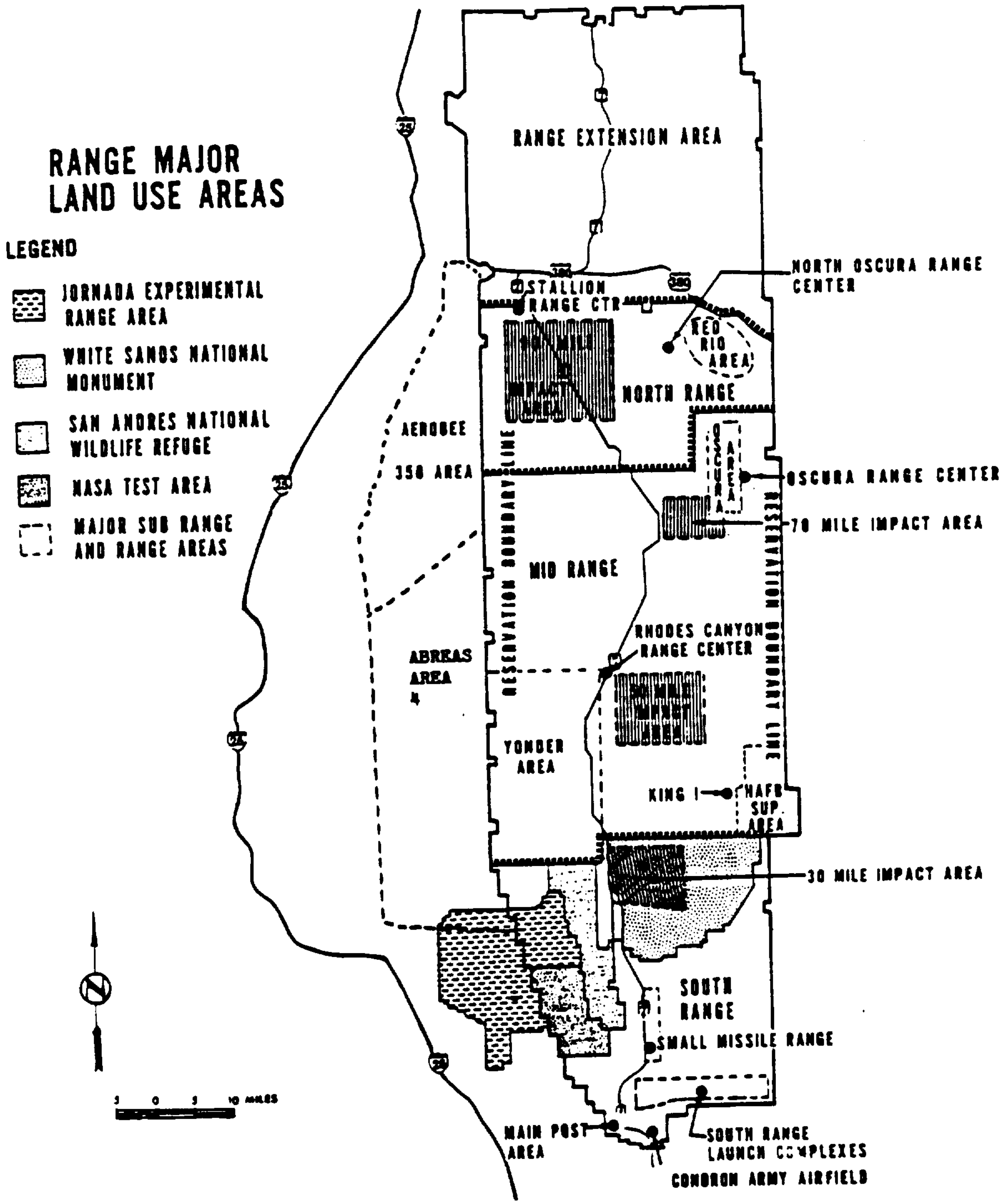


Figure 5.6-1. WSMR Map

procedures are slowed by unexpected difficulties such as tool breakage, procedural errors, or operational inefficiency. The final time increment is the additional time that may be required if the RRS design cannot be completely optimized for recovery operations such as hardware attachment locations, connector location and access, and GSE interfaces. All of the times identified have been estimated based on experienced judgement and by separating each step into sufficiently small activities to allow a reasonable evaluation of the time required to complete the activity.

5.6.1 Option 1, Helicopter Return and Direct EM Access

The first payload recovery and experiment access option uses helicopter transportation of the RRV from the landing site to the front of the Post-Recovery facility. There the RRV is placed on a transporter and moved inside the Post-Recovery facility for removal of the EM or the flight animals. When the EM or flight animals enter the laboratory section of the Post-Recovery facility, the access timeline is considered completed. The following section describes all of the activities anticipated for this operational procedure.

5.6.1.1 RRV Landing

This scenario starts with the RRV landing within the dispersion area of the predicted target point within the boundaries of WSMR. Tracking by WSMR range systems and onboard GPS navigation system should provide the ground recovery personnel information as to the actual drift direction of the RRV while it is in the terminal descent phase of the mission. Normally, the recovery personnel will be located outside the mid-point of the dispersion ellipse perpendicular to the orbit ground track.

A helicopter containing the hazard inspection and safing personnel will be aloft and downrange of the predicted target point to gain visual contact of the RRV. RRV location devices and GPS data are expected to aid in the acquisition of the RRV by the helicopter crew. Once the RRV has been sighted, the recovery personnel will deploy to arrive slightly upwind of the vehicle landing point. Upon ground contact of the RRV, the timeline for EM access operations will be considered to be initiated. After ground contact, the parachute will be automatically collapsed or released to avoid dragging the RRV on the ground. The time from ground contact until the arrival of the helicopter with the hazard inspection and safety personnel is expected to be from 5 to 15 minutes under good weather daylight conditions. This time may be extended to 25 minutes under nighttime minimum weather conditions.

5.6.1.2 Hazard Inspection and Safing

The first person on the scene at the landing site should be a suited hazard and safety team member with a propellant vapor detector to inspect for residual propellant leaks. Upon confirmation that no hazardous leaks are present, the vapor detector is left downwind of the spacecraft and a visual inspection of all pyrotechnic elements is conducted. Manual safing of the pyrotechnic circuits and inerting of location devices will be required before other tasks can proceed. One concern is that the RRV may still be too hot from reentry heating to allow unprotected technicians to manually work on the vehicle. Analysis will have to be performed to determine the range of temperatures expected for the RRV structure and components. If analysis indicates that hazardous structural temperatures may exist at landing, either provisions to accommodate recovery operations must be made or this step in the timeline may be greatly extended. Provided that no anomalies are found and that thermal conditions do not present a problem, the hazard inspection and safing should take from 10 to 25 minutes.

5.6.1.3 RRV Transportation Sling Installation

After the hazard inspection has been completed, the recovery personnel will attach a transportation sling to the RRV to allow it to be carried by a helicopter. This sling may be attached to the launch support attachment points, parachute harness attachment points, or a single point location. The design option to increase the number of attachment points yields improved stability while it is being transported but has the converse disadvantage of requiring more time to connect the hardware as the number of attachment points increase. It may also be necessary to connect power and thermal control interfaces from the GSE to the RRV. The need for these services at this time is subject to design study. This activity is expected to take from 5 to 20 minutes. Other activity occurring at the same time will be the recovery and storage of the descent parachute. Pickup and return of the parachute will be accomplished by assigned personnel supported by ground transportation and is not expected to affect the critical timeline.

5.6.1.4 RRV Helicopter Transfer

The helicopter transporting the RRV will engage the sling to its cargo hook and fly the RRV containing the PM back to the Post-Recovery facility. It will lower the RRV to a mobile transporter located on the apron in front of the Post-Recovery facility. Once the RRV is in the support cradle, the sling and any optional GSE will be disengaged. With transportation over the distance of 75 miles, it was found that transportation time became the critical factor in the timeline.

Discussion with personnel at Hill AFB indicated that the expected flight performance of a HH-53 helicopter with an external load varied from 60 to 90 knots. For this reason, it was felt that the location fo the Post-Recovery facility should be baselined to a location more central to the WSMR. One such location is the Holloman AFB which is located on the eastern side of the range. The other change was to limit mission orbits so that orbital paths would cross within 40 nm of the Post-Recovery facility. This resulted in a transportation time of 40 to 65 minutes allowing for aircraft performance and time for operations on both ends of the transportation process. Ability of available helicopters can carry a load the size, shape and weight of the RRV at these speeds without encountering aerodynamic instabilities must be verified by further aerodynamic analysis or tests to confirm the time required for this operation.

5.6.1.5 RRV Transfer to Post-Recovery Facility

Once the RRV is placed on the mobile transporter, it must be secured to the transporter before it is moved inside the Post-Recovery facility. The section of the Post-Recovery facility that contains the RRV is assumed to be adjacent to but separate from the section used for Post-Recovery experiment support. Reasons for the separation of work areas are that the RRV may still have propellants onboard, creating a potential safety risk, and the environment surrounding the vehicle may not be suitable for support of the post-flight scientific experiment activities. Propellant vapor detection, fire suppression support, and fans for air circulation are anticipated to be required in this facility in support of RRV operations. After the RRV is inside the facility, work platforms will be placed next to the RRV to provide access to the top of the PM. This activity is anticipated to require from 10 to 20 minutes.

5.6.1.6 Recovery System Canister Removal

The work platform will allow technicians to remove modules and equipment from the RRV without damaging the spacecraft. With access to the upper deck, the technicians will disconnect the wiring to the Recovery System canister and install caps on all connectors. Removal of the Recovery System canister will require unfastening structural attachments between the canister and the RRV structure. If the hard points for the parachute harness were located in the canister, then several high tensile strength fasteners would be required to join the canister to the RRV structure. An empty Recovery System canister should be light enough to be manually lifted from its installation point. This activity is anticipated to take approximately 10 to 20 minutes.

5.6.1.7 Access to EM

Technicians on the work platform are anticipated to only have to remove a simple device retaining the top of the PM pressure vessel containing the EM. Once the PM is opened, access is available to the animal cage or the entire experiment module. Removal of either the EM or the animal cage would require a hoist since the cage assembly alone weighs approximately 150 pounds. After the EM or animal cage is removed from the RRV, it is transferred to the laboratory part of the Post-Recovery facility thus completing the access timeline sequence. This final phase of the time critical timeline may take from 10 to 20 minutes to complete.

5.6.1.8 RRV Deactivation and Post-Access Operations

Deactivation of the RRV propulsion system and other post-access operations are not included in the timeline but involve the ground personnel, equipment, and facilities supporting the payload retrieval and access activities. For completeness, these operations will be described for estimating support requirements.

After the EM is removed from the RRV, additional operations such as propulsion system deactivation, recorded experiment data download, fluid sampling, and critical hardware removal must be accomplished. The RRV may be moved to a separate deactivation facility located near the other facilities to allow spacecraft post-recovery operations to be completed. The choice of facility use will largely be driven by ground safety and facility availability considerations. This activity is not time critical and is expected to take 24 hours to complete. The facility required for spacecraft deactivation must be well ventilated and have standard utility services in addition to fire support. Spacecraft GSE designed to drain and clean residual propellant from the propulsion system will be in the facility. Personnel to support the propulsion system deactivation will be provided. After the propulsion system is flushed and drained, a dry gas pad is placed in the system. Any additional safing required for pyrotechnic system will be accomplished at this time.

Downloading of the stored experiment data and images is envisioned to be accomplished by connecting a data interface connector and transferring the recorded data to ground equipment for support of the experiments. The flight recorder will probably remain with the vehicle for checkout and refurbishment at the refurbishment facility. Fluid sampling of the onboard fluids may be accomplished if it is necessary to support the experiments or vehicle post-flight analysis. Any other system requiring immediate deservicing is accommodated and all systems are sealed in preparation for transportation back to the refurbishment facility. Coordinated packaging and transportation of the RRV, its GSE, and the flight experiment hardware associated with the RRV is anticipated.

5.6.2 Option 2, Helicopter Return, PM Removal and EM Access

The second payload recovery and experiment access option is similar to the first option except that the PM is removed from the RRV outside the Post-Recovery facility and the PM is transported into the experiment laboratory. The steps from RRV landing through helicopter transfer are the same as the first option. This option reduces some facility requirements and may ease some ground safety concerns. The following describes the steps involved in the operational activity.

5.6.2.1 RRV Landing

This sequence in the recovery operation is identical with that described in the first option. All of the steps and consideration discussed also apply for this operation. The range of time estimated for this step of the operation should cover the same span of 5 minutes to 25 minutes specified in the first option.

5.6.2.2 Hazard Inspection and Safing

Hazard inspection and safing activities are also identical to those described in the first option. All safety considerations must be properly addressed before other steps are allowed to proceed. The time estimated for this step is the same 10 to 25 minutes specified in the first operation option.

5.6.2.3 RRV Transportation Sling Installation

The attachment of the sling for helicopter transfer of the RRV is also identical to that described for the first operation option. This process is expected to take the same 5 to 20 minutes to complete. This time is driven by the design of the sling and the number of attachment points required. Also parallel to this activity will be the recovery and storage of the parachute.

5.6.2.4 RRV Helicopter Transfer

Helicopter transfer of the RRV will proceed in the same manner as discussed in the first operational option. To keep the timeline consistent, the time of 40 to 65 minutes should also be used for this step of the operation. This step ends when the RRV is placed on the transportation support cradle in front of the Post-Recovery facility.

5.6.2.5 Recovery System Canister Removal

For this recovery operation option, the Recovery System canister removal will be on the apron in front of the Post-Recovery facility. This step is accomplished immediately after the RRV is secured in the support cradle to alleviate the need to use a facility to perform this activity. Safety procedures regarding detection of propellant vapors and fire suppression will have to be observed. The procedure involved in the removal of the Recovery System canister from the RRV will be the same as that described in the first operation option with the exception of its location and time sequence. Since the activity regarding the canister is similar, the completion of this step in the operation is also expected to take approximately 10 to 20 minutes.

5.6.2.6 PM Interface Disconnection

In this recovery operation option, the PM must be removed from the RRV and transported separately into the Post-Recovery facility. Access to the upper surface of the PM is available after the Recovery System canister is removed. At this point, interface connectors which provide power, data, oxygen, pressurized air, water, and launch support thermal service for the PM are disconnected. The power interface may be left until the last item to minimize the time without ECLSS thermal control. The RRV power system circuit breakers must be opened before the interface is disengaged. To minimize the time required to engage and disengage these interfaces, some of the interfaces may be designed for drop-in engagement with the PM. Some of the fluid interfaces may have conventional threaded fasteners unless low leakage quick disconnect fasteners are found to be suitable for the long duration space application. If conventional fasteners are used, each fitting must be capped and sealed to prevent entry of foreign material. Removal of the structural fasteners holding the PM to the RRV structure may be accomplished simultaneously with the interface disconnect process providing that the work platform provides adequate space for more than one technician. Depending upon the number of interfaces and the nature of fluid connectors used, it is anticipated that this task may require from 10 to 40 minutes to complete.

5.6.2.7 PM Removal and Transfer

Removal of the PM from the RRV requires that a sling be attached to the PM or a lifting point be built into the PM. A mobile crane positioned on the apron earlier will move over the PM and extract the PM from the RRV. The crane will then swing the PM clear of the RRV and transfer it to the Ground Control Experiment Module Support Cart. Any alignment guides necessary to assist in the installation of the PM into the GCEM Support Cart should be designed into the structure to minimize time required for this step. Once the PM is placed into the GCEM Support Cart, all of the interface connectors and structural fasteners must be reconnected to support the PM during its return to the Post-Recovery facility. After the interfaces are connected, power can be supplied by the GCEM Support Cart to the PM for thermal and atmospheric control of the EM. Assuming that the time required to reconnect the interface fasteners is the same as that to disconnect, this phase of the activity is expected to require from 20 to 50 minutes to complete since the transfer activity was added to the timeline.

5.6.2.8 PM Transfer to Post-Recovery Facility

Once the PM is placed in the GCEM Support Cart, it is moved inside the Post-Recovery facility. After the PM is inside the facility, work platforms will be placed next to the PM to provide access to the top of the PM. This activity is anticipated to require from 10 to 20 minutes.

5.6.2.9 Access to EM

Technicians on the work platform are anticipated to only have to remove a simple device retaining the top of the PM pressure vessel containing the EM. Once the PM is opened, it is assumed that access is available to the flight animals and the timeline is stopped. If the animal cage has to be removed from the EM, it would require a hoist since the cage assembly alone weighs approximately 150 pounds. Depending upon the operational procedure, this final phase of the time critical timeline can take from 10 to 20 minutes.

5.6.2.10 RRV Deactivation and Post-Access Operations

Deactivation of the RRV propulsion system and other post-access operations are not included in the timeline but involve the ground personnel, equipment, and facilities supporting the payload retrieval and access activities. For the purpose of completeness, these operations will be described for the purpose of estimating support requirements.

After the PM is removed from the RRV, additional operations such as propulsion system deactivation, recorded experiment data download, fluid sampling, and critical hardware removal must be accomplished. The RRV will be moved to a separate deactivation facility located near the other facilities to allow spacecraft post-recovery operations to be completed. The choice of facility use will largely be driven by ground safety and facility availability considerations. This activity is not time critical and is expected to take 24 hours to complete. The facility required for spacecraft deactivation must be well ventilated and have standard utility services in addition to fire support. Spacecraft GSE designed to drain and clean residual propellant from the propulsion system will be awaiting in the facility. Personnel to support the propulsion system deactivation will be provided to support the operation. After the propulsion system is flushed and drained, a dry gas pad is placed in the system. Any additional safing required for pyrotechnic system will be accomplished at this time.

Removal of flight and experiment data as well as sampling of fluids are expected to proceed in a manner very similar to that discussed in the first recovery option. Completion of this activity and preparation for shipment is not time critical and is expected to be coordinated with the return of the RRV and flight experiments.

5.6.3 Option 3, PM Removal at Landing Site and Transfer to Post-Recovery Facility

The third payload recovery and experiment access option considered consists of removal of the PM at the landing site and return by helicopter to the Post-Recovery facility. For this option, the RRV landing and hazard inspection steps remain basically the same but operations significantly change for the remaining steps. This option may avoid problems associated with helicopter transfer of the entire RRV but requires additional time, effort and equipment at the landing site. The following describes the activities and times anticipated for this operational procedure.

5.6.3.1 RRV Landing

The RRV landing dispersion control for this option remains the same as described for the two previous options. However, it requires the ground personnel and equipment to be near the target point before landing to maintain timeline control. The ground support personnel will consist of personnel handling a mobile crane capable of lifting the RRV, transportation personnel with a truck or trailer capable of carrying the RRV back to the Post-Recovery facility, and RRV technicians for spacecraft and experiment access.

A helicopter containing the hazard inspection and safing personnel will be aloft and downrange of the predicted target point to assist in gaining visual contact with the RRV. Once the RRV has been acquired by tracking, the ground and airborne personnel will deploy to arrive slightly upwind of the vehicle landing point. Upon ground contact, the timeline for access operations will be considered to be in effect. The time from ground contact until the arrival of the helicopter with the hazard inspection and safety personnel is expected to be the same as the previous option which makes it from 5 to 25 minutes depending upon landing system, lighting and weather considerations.

5.6.3.2 Hazard Inspection and Safing

The procedures and precautions involved in hazard inspection and safing are expected to be the same as those in the two earlier recovery operation options. For these reasons, the same time of 10 to 25 minutes is expected to apply for this step of the recovery procedure.

5.6.3.3 RRV Positioning and Stabilization

While the hazard inspection was in progress, the crane and transporter should have arrived. A sling is attached to the RRV to allow the crane to erect the RRV and place it on a transportation cradle on the transport vehicle. Retaining straps will be connected to secure the RRV on the cradle and the crane is disengaged from the RRV. A cradle and appropriate restraining devices are considered necessary GSE due to the shape of the baseline RRV. Due to the nature of this activity, it is anticipated that 10 to 30 minutes will be required to perform this task. Parallel to this activity, ground personnel will recover the parachute and place it into storage containers to protect it from damage.

5.6.3.4 Recovery System Canister Removal

Removal of the Recovery System canister for this operational option will take place at the landing site. This requires that the work platforms providing access to the upper deck be integral with the mobile transporter. The canister attachment method concerns discussed in the first recovery operations option also apply to this option. The time required to accomplish this procedure should require from 10 to 20 minutes to complete.

5.6.3.5 PM Interface Disconnection

Disconnection of the PM interfaces with the RRV is expected to be similar to that discussed in the second recovery operation option. It will primarily differ in the fact that it will be done earlier in the sequence and under field operation conditions. With these considerations in mind, this operation may take from 10 to 50 minutes to accomplish.

5.6.3.6 PM Removal and Transfer

Removal of the PM from the RRV requires that a sling be attached to the PM or a lifting point be built into the PM. The crane used earlier to lift the RRV on the cradle will be positioned over the PM and extract the PM from the RRV. The crane will then swing the PM clear of the RRV and transfer it to the GCEM Support Cart which should have been placed on the ground earlier. Once the PM is placed into the GCEM Support Cart, all of the interface connectors and structural fasteners must be reconnected to support the PM during its return to the Post-Recovery facility. After the interfaces are connected, power can be supplied by the GCEM Support Cart to the PM for thermal and atmospheric control of the EM. Assuming that the time required to reconnect the interface fasteners is the same as that to disconnect, this phase of the activity is expected to require from 20 to 60 minutes to complete since the transfer activity was added to the timeline.

5.6.3.7 PM Helicopter Transfer

The helicopter transporting the PM inside the GCEM Support Cart will engage its sling and fly them to the Post-Recovery facility. With transit over the distance of 40 miles and allowing time for operations on both ends of the transportation process, it is anticipated that 40 to 65 minutes will be required for transportation to the Post-Recovery facility.

5.6.3.8 PM Transfer to Post-Recovery Facility

Once the GCEM Support Cart is placed on the apron in front of the Post-Recovery facility, it must be towed directly into the experiment laboratory section of the Post-Recovery facility. After the GCEM Support Cart is inside the facility, work platforms will be placed next to the PM to provide access to the top of the PM. This activity is anticipated to require from 10 to 20 minutes.

5.6.3.9 PM Access to EM

Technicians on the work platform are anticipated to only have to remove a simple device retaining the top of the PM pressure vessel containing the EM. Removal of the animal cages would require a hoist since the cage assembly alone weighs approximately 150 pounds. At this point, access to the animals is available in the laboratory and the critical timeline is stopped. This final phase of the time critical timeline can take from 10 to 20 minutes.

5.6.3.10 RRV Return to Deactivation Facility

Return of the RRV from the landing point to a deactivation facility located at the NASA White Sands Test Facility is not included in the critical timeline but involves the ground personnel, equipment, and facilities supporting the payload retrieval and access activities. The mobile transporter with the RRV secured on a transportation cradle will return by surface routes to the NASA facility. Depending upon the landing location, the transportation phase of this operation may require several hours.

5.6.3.11 RRV Deactivation and Post-Access Operations

The deactivation and post-access operations are considered to be the same as those discussed in the second recovery operation option. A facility separate from the Post-Recovery facility will be utilized for this step since it minimizes risk to the experiment and support personnel.

5.7 RRS Recovery Operation Option Assessment

The three payload recovery and access options are compared in the following Tables 5.7-1, 5.7-2 and 5.7-3 as well as Figures 5.7-1, 5.7-2 and 5.7-3 to illustrate the time required to complete the operation from the time of RRV land contact until access is available to the flight animals by the experimenters. The tables and figures indicate the range of time estimated to accomplish each step of the operation. From the tables, we can see that the helicopter return of the RRS and direct access to the experiment module at the Post-Recovery facility (Option 1) has a significant time margin over the other two options and the minimum time is within the access time requirement limit. Since the last two options are at or exceed the access time limit, effort was focused on the first option to further refine details of the operation.

Table 5.7-1. Option 1, Helicopter Return and EM Access Timeline

Step	Activity	Min.	Ops. Unc.	Design Opt.	Max.
5.6.1.1	RRV Landing Landing contact until personnel arrival.	5	10	10	25
5.6.1.2	Hazard Inspection and Safing Propellant leak check, visual inspection, safe pyros, open circuit breakers.	10	10	5	25
5.6.1.3	RRV Transportation Sling Installation Connect sling attachments, recover parachute.	5	5	10	20
5.6.1.4	RRV Helicopter Transfer Engage sling, transport RRV, position RRV in cradle, disengage sling.	40	15	10	65
5.6.1.5	RRV Transfer to Post-Recovery Facility Attach restraints, move RRV to facility, install work platforms.	10	5	5	20
5.6.1.6	Recovery System Canister Removal Disconnect and cap wiring, remove structural fasteners, manually remove canister.	10	5	5	20
5.6.1.7	Access to EM Remove cover to PM, attach lift cable, remove animal cage, transfer animal cage to laboratory.	10	5	5	20
	Total Time (Requirement $\leq$ 120)	**90**			**195**

Table 5.7-2. Option 2, Helicopter Return PM Removal and EM Access Timeline

Step	Activity	Min.	Ops. Unc.	Design Opt.	Max.
5.6.2.1	RRV Landing Landing contact until personnel arrival.	5	10	10	25
5.6.2.2	Hazard Inspection and Safing Propellant leak check, visual inspection, safe pyros, open circuit breakers.	10	10	5	25
5.6.2.3	RRV Transportation Sling Installation Connect sling attachments, recover parachute	5	5	10	20
5.6.2.4	RRV Helicopter Transfer Engage sling, transport RRV, Position RRV in cradle, disengage sling.	40	15	10	65
5.6.2.5	Recovery System Canister Removal Position workstands, restrain RRV, disconnect and wiring, remove fasteners, manually remove canister.	10	5	5	20
5.6.2.6	PM Interface Disconnection Disengage power, disconnect interfaces, cap connectors, remove structural fasteners.	10	10	20	40
5.6.2.7	PM Removal and Transfer Position crane, attach cable to PM, extract PM from RRS, transfer PM to GCEM support cart, install fasteners, reconnect interfaces, turn on power and GSE support.	20	10	20	50

Table 5.7-2. Option 2, Helicopter Return PM Removal and EM Access Timeline (Cont.)

Step	Activity	Min.	Ops. Unc.	Design Opt.	Max.
5.6.2.8	PM Transfer to Post Recovery Facility Move PM into facility, position work platforms.	10	5	5	20
5.6.2.9	Access to EM Remove PM cover, attach hoist, remove animal cage	10	5	5	20
	Total Time (Requirements $\leq$ 120)	**120**			**285**

Table 5.7-3. Option 3, PM Removal at Landing Site and Transfer to Post-Recovery Facility Timeline

Step	Activity	Min.	Ops. Unc.	Design Opt.	Max.
5.6.3.1	RRV Landing Landing contact until personnel arrival.	5	10	10	25
5.6.3.2	Hazard Inspection and Safing Propellant leak check, visual inspection, safe pyros, open circuit brakers.	10	10	5	25
5.6.3.3	RRV Positioning and Stabilization Position crane and transporter, attach sling, lift RRV onto cradle, secure RRV, recover parachutes.	10	10	10	30
5.6.3.4	Recovery System Canister Removal Position workstands, disconnect and cap wiring, remove structural fasteners, manually remove canister.	10	5	5	20
5.6.3.5	PM Interface Disconnection Disengage power, disconnect interfaces, cap connectors, remove structural fasteners.	10	10	20	40
5.6.3.6	PM Removal and Transfer Position crane, attach sling to PM, extract PM from RRS, transfer PM to GCEM Support Cart, install fasteners, reconnect interfaces, turn on power and GSE support.	20	10	20	50

Table 5.7-3. Option 3, PM Removal at Landing Site and Transfer to Post-Recovery Facility Timeline (Cont.)

Step	Activity	Min	Ops. Unc.	Design Opt.	Max
5.6.3.7	PM Helicopter Transfer Engage GCEM Support Cart harness to helicopter, lift and transport to Post-Recovery Facility, lower cart and disengage harness.	40	15	10	65
5.6.3.8	PM Transfer to Post-Recovery Facility Move PM into facility, position workstands	10	5	5	20
5.6.3.9	Access to EM Remove PM cover, attach hoist, remove animal cage	10	5	5	20
	Total Time (Requirement $\leq$ 120)	**125**			**295**

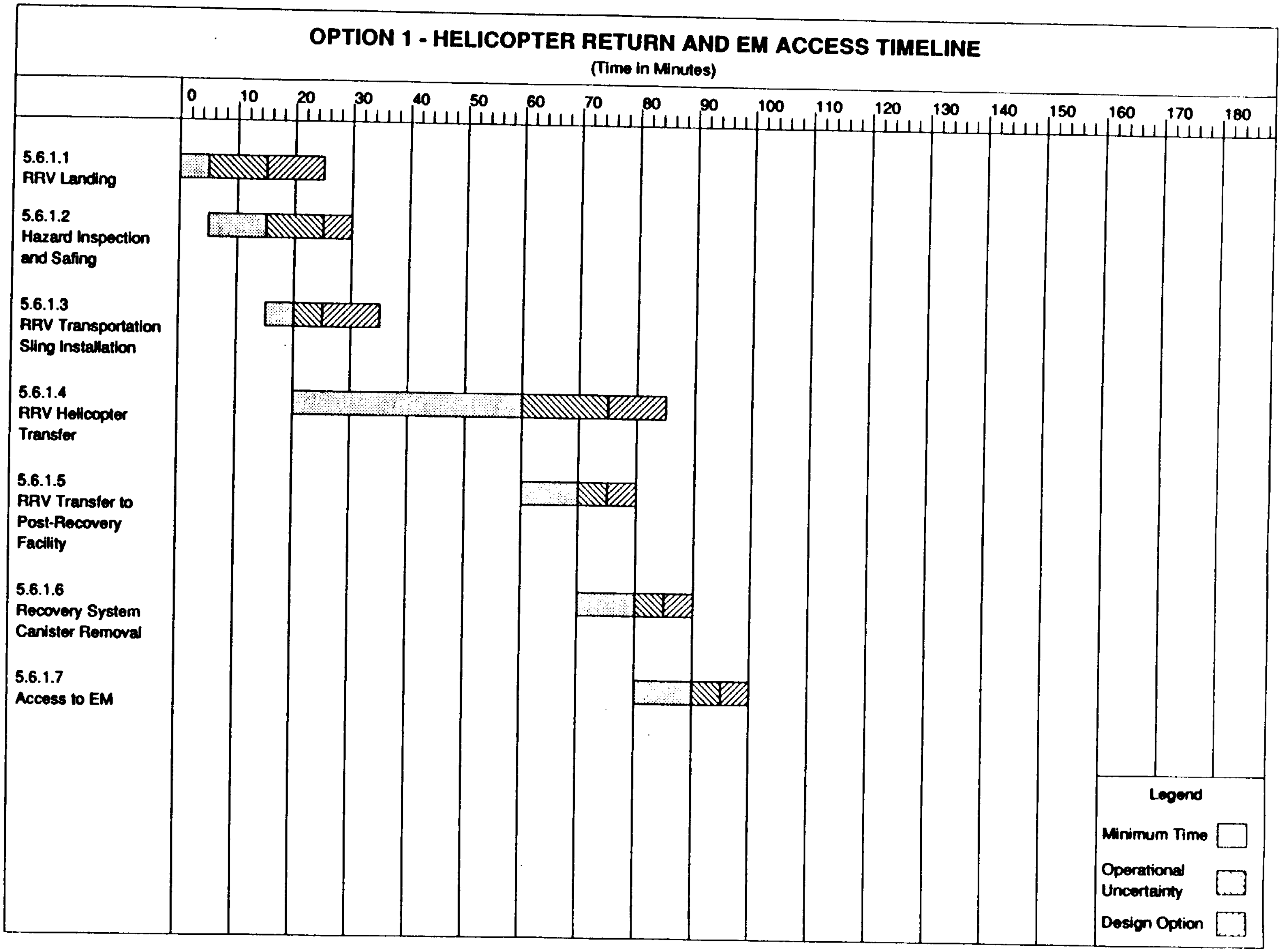


Figure 5.7-1. Option 1, Helicopter Return and EM Access Timeline

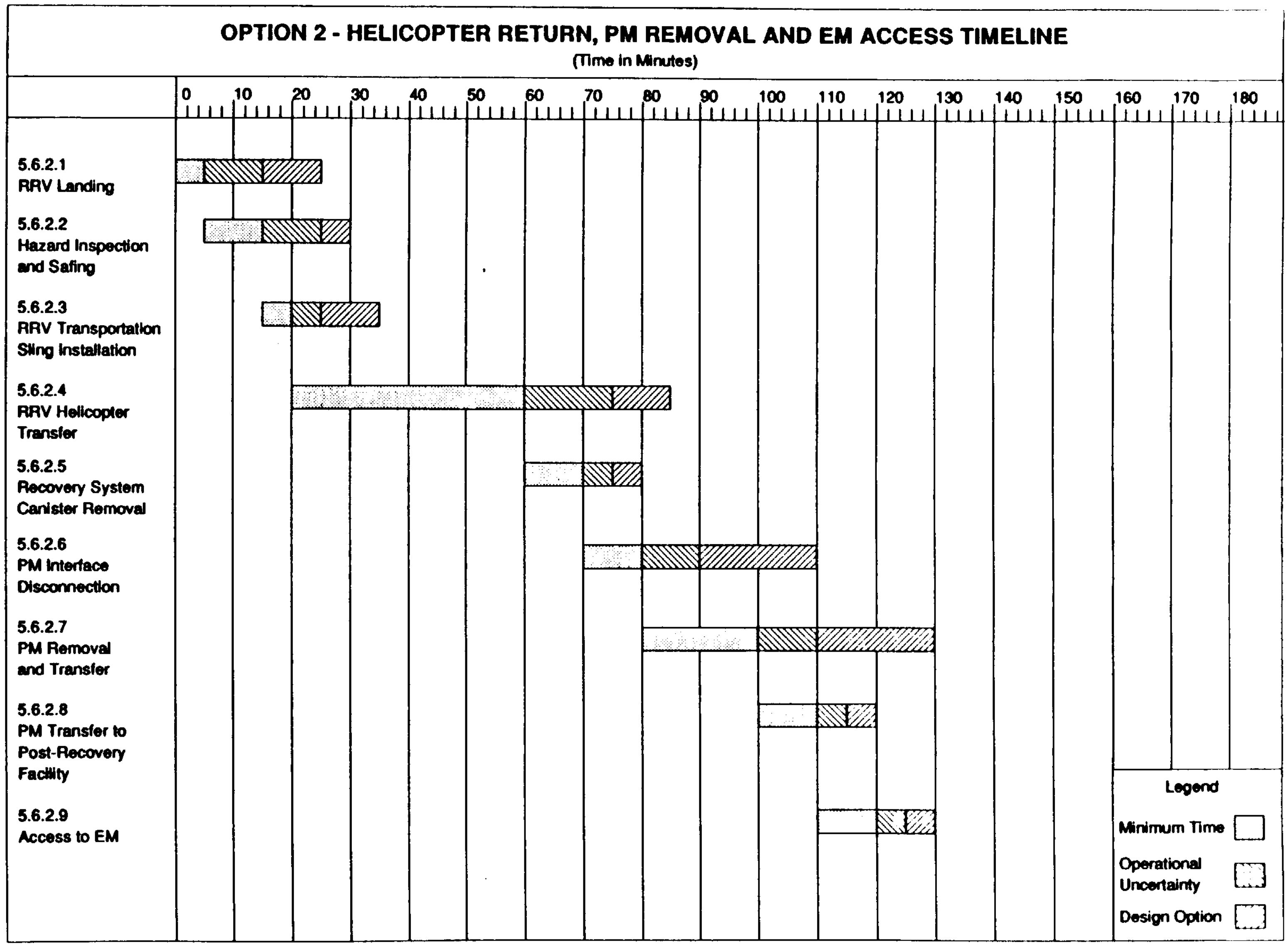


Figure 5.7-2. Option 2, Helicopter Return PM Removal and EM Access Timeline

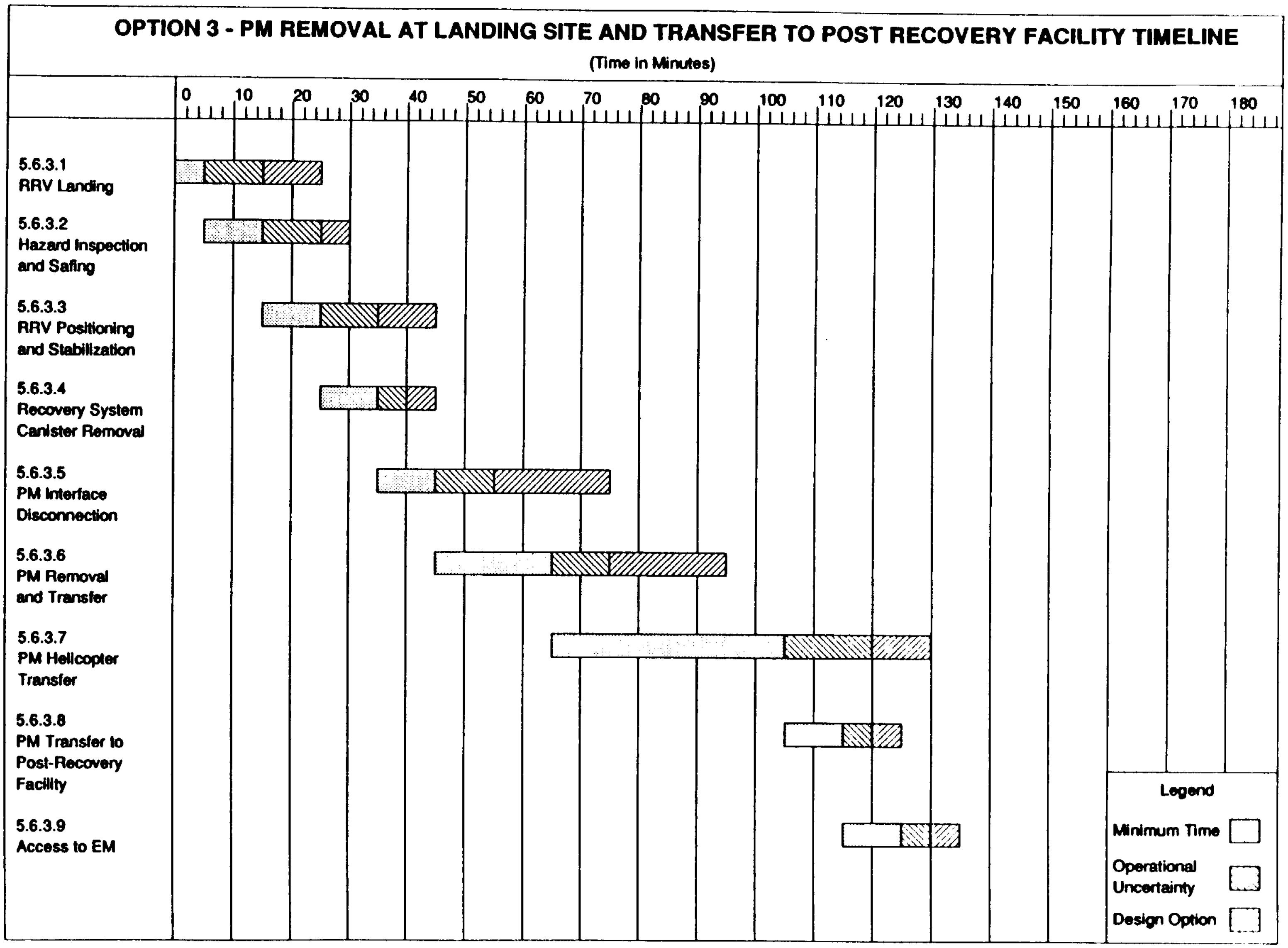


Figure 5.7-3. Option 3, PM Removal at Landing Site and Transfer to Post Recovery Facility Timeline

The range of time specified for each step in the recovery timeline were estimates considering both design and operational factors. At this time it is not considered very practical to try to refine the timeline values through establishment of average time values and RSS'd errors to arrive at the maximum probable time for the operation. In fact, it is uncertain whether or not the 120 minute access time requirement can be met with any reasonable assumption for contingencies. It is considered more practical to address the major timeline drivers and develop proper design and operational steps to insure that these items can meet or be less than the times indicated in the recovery timeline. Once further design definition has been completed for the RRV, this timeline should be reevaluated and efforts made to make sure that the total timeline will meet the access requirements with consideration for errors and contingencies.

An estimate of the facility support, manpower, ground support equipment, and vehicles needed to accomplish the payload recovery and experiment access was developed from the recovery timeline. The support required was grouped by the three main locations of recovery operations which were the RRV landing site, Post-Recovery facility area, and the RRV deactivation area. The first two locations are in direct response to the critical timeline whereas the RRV deactivation area support is a continuation of the recovery operation after the critical timeline events have been completed. Since all of these activities are in support of the recovery of the vehicle and flight experiments, they were addressed at this time. Table 5.7-4 lists the estimated nature and level of support required for each location.

5.7.1 Facility Support

The facility support for the RRV recovery operations covers three different locations. At the landing site, the main support required from WSMR is RRV tracking and operations communications. The tracking support is required to determine the location of the RRV during its terminal descent phase in order that the recovery personnel will be close to the touchdown point at the time of vehicle landing. Communications between the RRS ground station and the recovery operations personnel is required to receive GPS location data from the RRV. Additionally, communications between the various RRS ground support elements will be required during the course of the operation.

At the Post-Recovery facility, a helicopter landing area in front of the facility with adequate lighting for night operations is required. Site support for fire suppression is also desired once the RRV is in the area. An enclosed facility to provide weather protection for the RRV is required to perform operations for the removal of the EM or flight animals from the RRV. This facility should

Table 5.7-4. RRS Payload Recovery and Experiment Access Support

RRS Landing Site			
Facility Support -WSMR Tracking & Comm	RRV Personnel -Recovery Ops Director (1) -Hazard & Safing Tech (2) -RRV Systems Tech (2) -Parachute Recovery Tech (2)	GSE -Propellant Vapor Detector -Portable Lighting -RRV Tools -RRV Transport Harness -Parachute Storage Container -RRV Power & Thermal Support GSE (Optional)	Vehicles -HH-53 Helicopter -Truck
Post-Recovery Facility			
Facility Support -Helicopter Pad -Enclosed RRV Facility -Experiment Laboratory -Helo Pad Area Lighting -Fire Suppression Support -Overhead Hoist (5 Ton)	RRV Personnel -Recovery Ops Director (1) -Hazard & Safing Tech (2) -RRV System Tech (2) -Rigging Support Tech (2)	GSE -RRV Cradle & Restraints -RRV Workstands -RRV Tools -EM Lifting Sling -EM Transport Cart -RRV Power & Thermal Support GSE (Optional)	Vehicles -Mobile Transporter -Aircraft Tow Truck
RRV Deactivation Facility			
Facility Support -Enclosed RRV Facility -Fire Suppression Support -Overhead Hoist (5 Ton) -Chemical Dump Area	RRV Personnel -Recovery Ops Director (1) -Hazard & Safing Tech (2) -RRV System Tech (2)	GSE -RRV Cradle & Restraints -RRV Workstands -RRV Tools -RRV Propulsion System Service Cart	Vehicles -Mobile Transporter -Aircraft Tow Truck -Fork Lift

be separated from the laboratory facilities used to perform post-flight experiments on the animals. A hoist capable of removing the EM as well as lifting the RRV is required in the facility.

To support deactivation of the RRV, a facility with weather protection, adequate ventilation, and safe separation distance from other activities is required. Fire suppression support is also required at this facility. This facility may be the same as the one initially used for EM removal as long as the safe separation distance from the experiment laboratory is maintained. An overhead hoist or crane capable of lifting the entire RRV is required to assist in the repositioning of the RRV for return shipment to the refurbishment location. After these operations are completed, a dump area must be provided for disposal of the neutralized propellants and contaminated flushing fluids.

5.7.2 RRV Personnel

The personnel listed in this section describe those individuals who are directly involved with contact with the RRV during recovery operations. The RRV personnel identified are expected to be some of the same individuals at each location. Site support personnel such as those individuals providing security, communications, fire protection, vehicle operation, and aircraft operations are not enumerated. The recovery operations team at the landing site will consist of the operations director, hazard and safing technicians, RRV system technicians, and parachute recovery personnel. At the Post-Recovery facility, these personnel may be augmented with individuals to assist in the removal and engagement of slings, retention devices, and handling of the RRV components. It is expected that the same individuals will be used to complete the deactivation of the RRV and preparation of the equipment for return transportation to the refurbishment location.

5.7.3 GSE

GSE items used in one location during the recovery operation may be carried through each of the following locations if required. The items identified represent the major items that must be available at each location. At the landing site, the first items needed are the propellant vapor detectors and protective garments for the hazard and safing personnel. Portable lighting may be required if the operation is performed at night. A harness to connect the RRV to the helicopter for transport will have to be provided. If it is necessary to provide power and thermal support to the RRV immediately, then air transportable GSE will be required to support those needs. Any special tools for engagement of this hardware is also required. A container to store the parachute is desired to protect it against transportation and handling damage.

The RRV cradle and restraints to secure it to the transportation vehicle should be waiting at the Post-Recovery facility. Easily attachable or integral workstands to allow rapid access to the EM are necessary to keep the timeline to a minimum. Hardware to lift the EM or animal cages from the RRV, and an EM transportation cart to move the EM into the experiment laboratory are also necessary. If the RRV requires continued power and thermal control support during this operation, the source used during helicopter transportation will be removed from the helicopter and carried with the RRV.

The RRV cradle and transporter will be retained during the deactivation operation. The primary additional GSE will be the RRV propulsion system service cart with its associated equipment. All of the GSE used in the previous locations will be gathered for packing and return after the deactivation operation is completed.

5.7.4 Vehicle

One HH-53 helicopter or equivalent unit will be used in the location of the RRV and transportation to the Post-Recovery facility. Supporting the landing site will be a truck to pick up the parachute container and any personnel necessary on the ground to connect the helicopter to the transportation sling. At the Post-Recovery facility, a mobile transporter capable of carrying the RRV is required. This vehicle may be a truck, truck and trailer, or other transporter capable of supporting the RRV and providing sufficient work area to perform experiment access operations. A tow motor or truck may be required to move the EM package from its removal point to the experiment laboratory. The mobile transporter is needed to move the RRV to the deactivation area and finally to the shipping point for return to the refurbishment location. An aircraft tow truck or other appropriate vehicle may be necessary to move the RRV propulsion system service cart in and around the deactivation work area. A fork lift will be required to load all of the GSE container and equipment for return shipment.

5.8 RRS Design and Operation Considerations

Several RRS design and operation options have been identified that directly affect the proposed RRV recovery and experiment access timeline. A summary of these options is given in Table 5.8-1 of this report. The operations options identified for deorbit targeting were primarily in

Table 5.8.1. Design and Operational Options Affecting Recovery Timeline

Activity	Design and Operation Options
RRV Landing	• Deorbit Targeting - Mission termination orbit selection - Entry targeting dispersions - Wind drift compensation targeting • Parachute System Design - Conventional parachutes - Gliding parachutes • Parachute deployment altitude • RRV Position Determination During Terminal Descent - WSMR range tracking - GPS position feedback - Visual location aids
Hazard Inspection and Safing	• Propulsion System Design - Propellant dump and purge - System depressurization
RRV Transportation Sling Installation	• RRV Transportation Sling Design - Number of attachment points - Method of attachment - Location of attachment points • RRV Power and Thermal Control GSE - Interface connector design - GSE unit size and weight
RRV Helicopter Transfer	• Helicopter Performance • RRV Aerodynamic Stability - RRV shape - Transportation sling bridle length - Number and location of RRV attachment points • Constraint on Landing Site Area
RRV Transfer to Post-Recovery Facility	• RRV Cradle and Retention System Design • RRV Work Platform Design
Recovery System Canister Removal	• Location of Recovery System • Canister Attachment Method • Parachute Harness Attachment Location
Access to EM	• PM Pressure Vessel Closure Design • EM and Animal Cage Design

the area of mission operations related to mission termination orbit selection and initial mission orbit parameter planning. These two factors strongly drive the location of the landing target point. Another factor is the control of the landing dispersions while the vehicle is on its parachute. This is affected by the design choice of the parachute system and operational methods used to compensate for wind drift. A conventional parachute system could minimize wind drift by lowering the opening altitude of the main parachute. The major timeline driver is the transportation time between the landing site and the Post-Recovery facility. Operational factors include the physical time required to connect and disconnect the sling and travel time affected by weather conditions. Design factors are mainly those that affect the operating velocity of the helicopter with its attached load.

In each step of the recovery operation, design details affecting the timeline were identified. A design choice which impacts the timeline is the selection of the method of attachment of the RRV to the helicopter. If PM removal is considered, the design choice of the interface connectors has significant impact on the time required to disconnect and reconnect all of the service interfaces. The other design choices were included as considerations that should be addressed as design detail is refined.

5.9 Conclusions and Recommendations

The development and analysis of the recovery and EM access timelines indicate that it is feasible to accomplish the operation within the 2 hour limit specified. For the purpose of continuation of the study effort, it is recommended that the first option of helicopter return of the RRV and removal of the EM at the Post-Recovery facility be baselined. It is also recommended to constrain the landing sites to be within the range of 40 n.m. from the Post-Recovery facility and to move the Post-Recovery facility to a more central location than the NASA Test Facility. Analysis of RRV anticipated post-landing thermal history is necessary to insure that it does not present a hazard or hinder the performance of the operation. Each of the design and operation options identified should be pursued in the further refinement of the vehicle design and operations process. After design options are analyzed and selections made, a better timeline with accurate estimates for potential time variation can be performed to assure that the timeline does not exceed the required 2 hours with reasonable allowances for contingencies.

In the event that further analyses indicate that sufficient time will not be available to accomplish the operation within the required 2 hours with allowance for contingencies, the fourth option presented in the beginning of this report be developed to identify the activities, times, equipment, personnel, and facility support necessary to meet the science objectives.

It is also recommended that NASA coordinate range scheduling and range usage priorities to assure that top priority be given to support the RRS mission during critical periods following launch and preceding planned landing. A lower priority for range usage and recovery support can be used for the majority of the mission duration where the need for rapid support and range clearance is not as critical an issue. This is necessary to share the range with other users and to minimize the operational cost of maintaining range and recovery personnel on immediate standby for the duration of the mission.

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